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Feasibility of scallop enhancement and culture in Australian waters

Mike Dredge, Peter Duncan, Mike Heasman, Bill Johnston, Lindsay Joll, John Mercer, Duncan Souter and Ted Whittingham

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Feasibility of scallop enhancement and culture in Australian waters

Authors in alphabetical order

Mike Dredge[1], Peter Duncan[2], Mike Heasman[3],
Bill Johnston[2], Lindsay Joll[4], John Mercer[5],
Duncan Souter[6], Ted Whittingham[7].

[1] Queensland Fisheries Service, Southern Fisheries Centre, Deception Bay, Queensland.

[2] Agency for Food and Fibre Sciences, Department of Primary Industries, Bribie Island Aquaculture Research Centre, Queensland, now Sunshine Coast University, Maroochydore.

[3] New South Wales Fisheries, Port Stephens Fisheries Research Centre, Taylors Beach, New South Wales.

[4] Western Australian Fisheries Department, 168 St. Georges Tce, Perth, Western Australia

[5] Marine and Freshwater Research Institute, Victorian Department of Fisheries, Queenscliffe, Victoria.

[6] Queensland Seafood Industry Association, P.O. Box 392, Clayfield, Queensland.

[7] Hervey Bay Fisheries, P.O. Box 1470, Gladstone, Queensland.

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Contents

Note: Appendices 2, 3 and 4 are available from the FRDC library upon request.

Development of a business plan for enhancement/ culture of scallops in Australian waters

Principal investigator

Michael Dredge, Regional Manager, Queensland Fisheries Service, Department of Primary Industries, Southern Fisheries Centre, Deception Bay 4508, Queensland

Objectives

Phase 1

1. Identify key operational procedures and potential operational and bio-technological bottlenecks associated with successful and unsuccessful scallop enhancement and culture operations.
2. Identify critical financial, social and biological risks associated with enhancement and culture of saucer scallops in subtropical Australian waters and commercial scallops in southern waters.
3. Undertake a preliminary feasibility study and cost-benefit analysis for enhancement and culture of saucer scallops in subtropical Australian waters and commercial scallops in southern waters, based on outcomes of Objective 1.
4. Develop business plans (operational procedures, financial framework and timetable) for conducting a financially viable and ecologically sustainable saucer scallop enhancement or culture program in subtropical waters of Australia and/or for commercial scallops in southern waters.

Phase 2

1. To facilitate an agreed implementation model for saucer scallop enhancement ventures in Queensland and Western Australia.
2. To discuss how this preferred implementation model would be developed, including identification of industry and government responsibilities, information needs and research priorities.
3. To develop an agreed schedule for timing of each development step that is consistent with the business plan.
4. To identify the planned outcomes and the performance measures for the business plan.
5. To finalise the business plan to incorporate stakeholder comments and outcomes of a workshop.

Non-technical summary

Key words: Saucer scallop, commercial scallop, *Amusium, Pecten,* enhancement, feasibility.

A working party of persons with technical and practical experience in scallop biology, hatchery technology, economics, management, fishing operations and processing technology was convened to develop a study on the feasibility of enhancing and culturing saucer scallops (*Amusium balloti*) in subtropical waters, and commercial scallops (*Pecten fumatus*) in temperate waters, of Australia. The working group met in two informal workshops and undertook a study tour of a successful enhancement operation in New Zealand.

The working party has developed a feasibility study and outline of a business plan for saucer scallop marine ranching and enhancement, and has developed an outline for procedures which could be used when undertaking scallop culture and enhancement. Extensive economic modelling has been used to evaluate both procedures.

The working party:

- reviewed developments in scallop culture and enhancement that have taken place globally;
- identified techniques, governance and potential bottlenecks for enhancement operations;
- identified social and biological risks and information gaps associated with scallop enhancement and culture operations;
- undertook detailed economic modelling of scallop culture and enhancement operations;
- developed potential business plans under which scallop enhancement and culture operations might take place and be managed;
- completed a workshop designed to facilitate the commercialisation of saucer scallop ranching in Queensland and Western Australia, and explored potential linkages between research and development capabilities in the two States.

On a global basis, we found that scallop culture has been attempted in first and third world economies with very mixed success. There has been little consistency of operational conditions or economies for scallop culture operations that have succeeded. Successful operations could be associated with low labour costs, prolonged cultural and economic commitment to scallop culture, unique and favourable environmental conditions or disregard for long-term environmental impact. Unsuccessful operations, on the other hand, were often undercapitalised, lacked long-term commitment, or were based on species with very slow growth and prolonged lags between settlement and growth.

Marine ranching or enhancement of *A. balloti*, rather than hanging cage culture, appears to be economically and socially feasible. A marine ranching or enhancement operation would be based upon hatchery-reared scallops in its initial and intermediate stages of development. Economic models suggest that a marine ranching operation aimed at producing 100 tonnes of scallop meat per year would be highly profitable, with a 20-year project run generating Internal Rates of Return (IRR) of 59% for both low and high-risk management operations, and having Benefit-Cost (B:C) ratios of 2.6–2.7. The low and high-risk options involve either running a pilot operation before committing to a full commercial operation (low risk), or going straight into a full commercial operation following a Research and Development phase (high risk). The predicted IRRs and B:C ratios are considerably higher than returns that have been modelled for other aquaculture operations and business ventures, to the extent they needed to be treated with some caution. We have reviewed model input costs and processes, and conclude that they are reasonable assumptions of reality, or identified key areas of uncertainty, and conclude that the potentially super-normal profits appear to be linked to the high price and rapid growth rate of *A. balloti.*

The only significant social implications that involve potential or perceived loss of social amenity from a marine ranching or enhancement operation based on *A. balloti* are associated with conservation and policing issues. The Great Barrier Reef Marine Park Authority, for example, has made it clear it has philosophical difficulties with fisheries enhancement operations of any type. We believe that subject to proper genetic and disease protocols, there will be minimal risk of adverse environmental impacts from a saucer scallop marine ranching or enhancement operation. There would, however, be considerable economic and social gains to be made from a successful marine ranching or enhancement operation. There are areas outside the Great Barrier Reef Marine Park and in

Western Australian waters that would be suitable and available for marine ranching or enhancement. Conservation interests in Western Australia have not been so extreme in their views.

We identified specific deficits in information and technology requirements for marine ranching or enhancement of *A. balloti* in Australia that need to be addressed before economically viable operations can be developed.

While *A. balloti* has been spawned and reared to a size large enough for re-seeding, there will be a development phase required to develop and translate hatchery technology to a consistent and fully commercial-scale operation. We have made a number of assumptions about natural mortality rates of *A. balloti* at given sizes, but these assumptions are based on a limited factual basis and need testing. There is a need to determine optimum size of release, and develop transport procedures to take very large numbers of scallops from hatcheries to re-seeding sites.

A marine ranching operation could be conducted as a single integrated operation, owned and managed by a single business entity or public company, or be run as a consortium or cooperative of fishers and processors. The organisational structure and allocation of risks would be much easier to manage should a single entity operate an enhancement operation for saucer scallops, but a cooperative organisation would probably have greater social benefit in regional areas. Enhancement of a scallop stock for the general benefit of the fishery is feasible but organisationally more complex in terms of management, social implications and cost recovery.

Translating the conclusions of the working group to an operational industry development process using saucer scallops was explored in a workshop that was attended by private enterprise and government employees from Queensland, Western Australia and New South Wales. Participants from the workshop reviewed progress being made by a Western Australian company developing a marine ranching operation off Geraldton. Hopefully, Queensland participants were able to get a realistic idea of the time frames, costs and expertise required for a hatchery-based ranching operation.

The Western Australian government has developed procedures for authorising a scallop ranching operation and Queensland government participants started assembling the framework of an approval process for marine ranching during the workshop.

A Queensland-based consortium has agreed to establish a company with objectives based on the idea of undertaking R&D, and commercialising the ranching of saucer scallop. They have employed a consultant to develop the outlines of a business plan and initiate the process of approvals. Government support and funding opportunities for a re-seeding operation were identified. Site selection procedures, incorporating decision rules for both hatcheries and ranching sites, were initiated and an initial attempt to develop a business outline – time lines for specific activities, budgets and pilot-scale operations – was commenced.

Issues that were identified as needing further attention included key information gaps on saucer scallop biology, which were identified but not fleshed out in detail. Development of research priorities, a research risk assessment (i.e. how much knowledge is needed vs how much time and cost venturers are prepared to risk in the knowledge of specific information), and a national approach to research were considered, but only in limited detail. Discussion of hatchery protocols and requirements was limited, as was discussion on hatchery engineering and site location. The development of a national approach to saucer scallop ranching was not explored in any detail, but was implicit in a number of discussions held during the workshop.

There is obvious scope to keep working on these issues after the workshop, given the networks that have been established as a consequence of the workshop.

Saucer scallop ranching could become a test bed for enhancement operations in Australia. The species has rapid growth, is sedentary after settlement, has high meat value and demands considerable labour for its production and processing. It is unusual amongst shellfish, in that it has never been recorded as transmitting any form of dinoflagellate-based toxin poisoning. Early indications are that the species will not require extensive work for hatchery-reared spat to be identified. The species therefore lends itself to culture on the basis of economic, social and environmental justification. If ranching operations do proceed, there is a good case for research agencies and fisheries and environmental management bodies to advise, support and monitor the operation on a national basis.

For saucer scallop culture to become a reality there will be a need for long-term commitment by private enterprise, research providers and funding agencies. Environmental management agencies, the existing catching sector and the public at large will need to be aware, and supportive, of proposed ranching and culture operations.

The working group also examined the operational procedures and potential profitability of culturing (by hanging cage culture) or enhancing *P. fumatus*. Hanging cage culture techniques are well known and developed. Provided that spat could be sourced from open water collection, hanging cage culture operations could be economically successful at relatively small scales and with relatively low risk. Enhancing *P. fumatus* populations via re-seeding would be a far less certain operation in economic terms, particularly if hatchery-reared spat were required. Natural mortality rates for the species have not been described but may be highly variable according to both site and seeding density. Whilst hatchery techniques are well developed, an enhancement operation using hatchery-reared spat would require considerable investment, have a prolonged delay between investment and return and could only be seriously considered with appreciable government support.

1 Models for scallop aquaculture and enhancement and their potential application to saucer scallops and commercial scallops

Scallops have become the basis for some of the world's largest enhancement and mariculture industries. China, for example, is producing in the order of 1 500 000 tonnes of (whole) scallop through mariculture (hanging cage culture) operations at this time, and Japan, which has an extended history of scallop enhancement and mariculture, currently produces approximately 500 000 tonnes of whole scallop annually. Chile developed a successful cage culture operation that produces in excess of 20 000 tonnes of (whole) scallops annually, after a development phase of less than four years. At the same time, attempts to enhance or culture scallops in other countries, including Ireland, Scotland, France and Canada appear not to have met with the same level of commercial success to this time.

Most scallops are cultured using two fundamentally different procedures. The first involves deployment of scallop spat in cages hung on long lines in the sea, or directly fixing scallop spat to suspended drop lines. Hanging cage culture involves a range of cage types, spat collection procedures and growout procedures, but is essentially an intensively managed mariculture operation.

The alternative procedure involves the deployment of spat on the seabed and their subsequent harvest after a growout phase. The significance of terminology for such a form of stock enhancement cannot be ignored when discussing the basis for, or rationale behind, the artificial stabilisation or increase of a fished population (Leber 1999). The terminology applied to a range of enhancement and culture methodologies has been inconsistent, and this has the potential to generate confusion and misunderstanding. Bartley (1999) defined marine ranching as the practice of producing early life-history stages of an animal in a hatchery for eventual release into natural or modified (aquatic) habitats. In that sense, perhaps stock enhancement can be defined similarly, except that the enhanced stock is originally sourced from the natural environment. There is, therefore, a clear distinction between the source of stock, one based on improving survival of natural stock through on-growing after vulnerable life stages or in protected areas and the other using artificially sourced stock to increase the fishery beyond natural recruitment.

We have had to vary these definitions when considering enhancement or marine ranching operations in an Australian context, particularly in relation to saucer scallop enhancement. We believe any form of enhancement based on saucer scallops will rely upon hatchery-reared animals. A re-seeding operation confined to a legally defined area, and to which fishing access is restricted to the business enterprise running the operation has been defined as *marine ranching*. A re-seeding operation that allows access by an entire fishery and involves some form of *a priori* or *a posteri* cost recovery has been defined as an *enhancement operation*.

These definitions are important because they put the biological, ecological, social and financial considerations of a re-seeding program into context during discussion and evaluation.

1.1 Potential sources of juvenile scallops (spat)

Hanging cage culture, marine ranching and stock enhancement operations require significant quantities of juvenile scallop (spat) for growout or re-seeding, depending upon the magnitude of the enhancement operation and natural mortality rates.

For example, 35 million spat were released during initial enhancement trials in France in 1983. This figure increased to 800 million by 1995 (Fleury *et al.* 1997).

Similarly, in Japan, seeded quantities of spat around Hokaido alone amounted to 2500 million in 1990 (Ito 1991).

Spat may be either sourced from the wild or from hatcheries. The highly successful Japanese enhancement and aquaculture operations (Ito 1991), based principally on *Patinopecten yessoensis*, are now based exclusively on wild-caught spat. The development of viable wild-spat collection was actually the catalyst for the successful scallop production industry that was to follow.

The majority of scallop ranching and enhancement programs have utilised naturally occurring juvenile sources exclusively or, occasionally, combined with a smaller hatchery-produced component. The principal reason for this is the lower cost of wild collection, compared to hatchery rearing, of spat.

Scallops typically undergo a 2–3 week larval phase, during which planktonic dispersion acts to spread the new recruitment beyond the spawning areas and depending on hydrographic factors, disperse them widely or concentrate them in new areas. Thus, dependent on the consistency of water movement, certain areas may regularly recruit juveniles, thereby providing the location for significant spat collection operations. This predictability of spat collection in certain areas has been recognised as being an important feature of successful enhancement and aquaculture operations, e.g. Japan (Ventilla 1982, Ito 1991), New Zealand (Bull 1990a). Similarly, the converse, unpredictable open-water spat collection has resulted in constrained or unsuccessful aquaculture operations, e.g. Canada, France, Scotland, Ireland and Norway (see individual national sections in Section 3).

A key requirement for wild collection of scallop spat is the presence of a sustained and strong byssal attachment phase at the end of the larval cycle, which ensures the retention of juveniles on spat collection devices (Ventilla 1982).

Scallop species that have been cultured on a worldwide basis include:

- *Pecten maximus*
- *Pecten fumatus*
- *Pecten novaezelandiae*
- *Patinopecten yessoensis*
- *Placopecten magellanicus*
- *Patinopecten caurinus*
- *Chlamys farreri*
- *Chlamys nobilis*
- *Chlamys rubida*
- *Chlamys hastata*
- *Aequipecten opercularis*
- *Argopecten gibbus*
- *Argopecten irradians irradians*
- *Argopecten irradians concentricus*
- *Argopecten purpuratus*

All of these species have strong, sustained byssal attachment and can be collected from open water or produced in hatcheries in large quantities with relative ease, again due to the byssal attachment phase (Allen 1979, Paul 1985, Young et al. 1990, Bourne 1991, Bull 1990b, Ito 1991, Lou 1991, Naidu 1991, Rhodes 1991, Laing & Psimopoulos 1998).
The same spat collection devices are employed in open water and in the hatchery at the end of the planktonic larval phase to allow for collection of large spat numbers through settlement on suitable substrate materials with large surface areas. Spat of byssal-attaching species can then be ongrown to significant size (10–15 mm) within the spat collection bags and transferred directly to intermediate culture or a re-seeding site.

By contrast, species of the scallop genus *Amusium* have, until recently, been thought to have no significant byssal attachment phase, thereby precluding the option of open water spat collection (Kettle 1984, Sumpton et al. 1990, Robins-Troeger & Dredge 1993).
This also had significant implications for successful production of large numbers in hatcheries in the absence of novel techniques for holding large numbers of unattached spat.

Despite this, hatchery production of saucer scallops, *Amusium balloti*, has been investigated in studies including that of Rose *et al.* (1988) and, notably, Cropp (1993). This work achieved some success and demonstrated the potential for large-scale production, although the work terminated prior to the complete development of a commercially viable production process.

Very little work on *A. balloti* has occurred since that time until the recent studies at Bribie Island Aquaculture Research Centre as part of a joint DPI/UQ collaboration, and work in a private Western Australian hatchery (McGowan pers. com.). This work has confirmed the potential for hatchery production suggested by Cropp (1993) and, significantly, has identified an extended, but highly transitional, byssal attachment in this species, thereby providing additional options for hatchery production. The consequence of this work is the identification of scope for further development of methodologies for large-scale spat production, thereby making the concept of marine ranching and enhancement a viable possibility.

1.2 Potential culture and production methods

Once a source of spat has been established a variety of techniques for growout to market size are available. Scallop aquaculture worldwide has utilised several methodologies, but they are based on the following principles:

- Suspended or hanging cage culture
- Bottom culture
- Marine ranching and enhancement (restocking, sowing and harvest).

1.2.1 Suspended or hanging cage culture

The basis for suspended culture involves the placement of suitably sized spat or juveniles into net cages of various design that are attached to a dropper line.

Net cages

Originally based on Japanese techniques, these generally take the form of either pearl nets or lantern nets (Figure 1.1, A & B). Pearl nets are discrete cages connected in series and accessed from the top or sides. Lantern nets are stacked platforms surrounded by a net sock, in which the scallops rest. Pearl nets are more expensive than lantern nets but have the advantage of being made up as separate units and are able to be moved for cleaning or reducing scallop densities when required.

There is occasional use of other net structures in Japan, such as pockets nets (also used for pearl oysters) and hanging baskets (Ito 1991), although these are less common both in Japan and elsewhere.

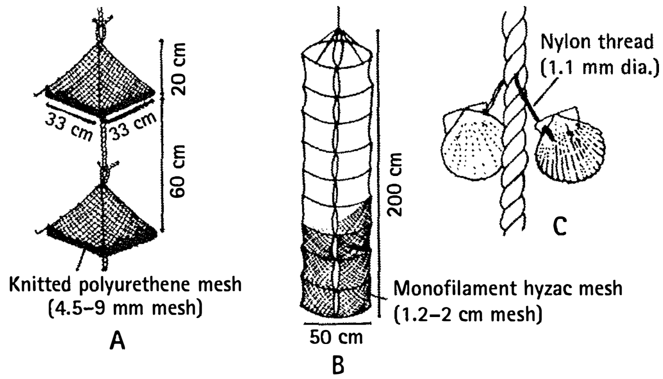

Figure 1.1 Principal growout methods for scallop aquaculture (Modified from Ito & Byakuno 1990)

Attachment to droppers

There are two basic forms of growout using direct attachment to a suspended line or surface. Ear hanging (Figures 1.1, 1.2) was developed in Japan, and forms the basis of some of their successful scallop industry (Ito 1991). This method has been adopted or modified in various other countries, including Scotland (Paul 1988), Spain (Roman & Fernandez 1991) and Canada (Dadswell & Parsons 1991).

Disadvantages of this method include external fouling of shells and growth and mortality problems resulting from the drilling procedure (Hamada *et al.* 2000). Scallops of around 50–55 mm are used to minimise these problems, (Ventilla 1982, Dadswell & Parsons 1991) which tend to add to the overall costs because of the extended intermediate growout phase in suspended net culture. The process requires specialised machinery and intensive labour usage, adding to costs.

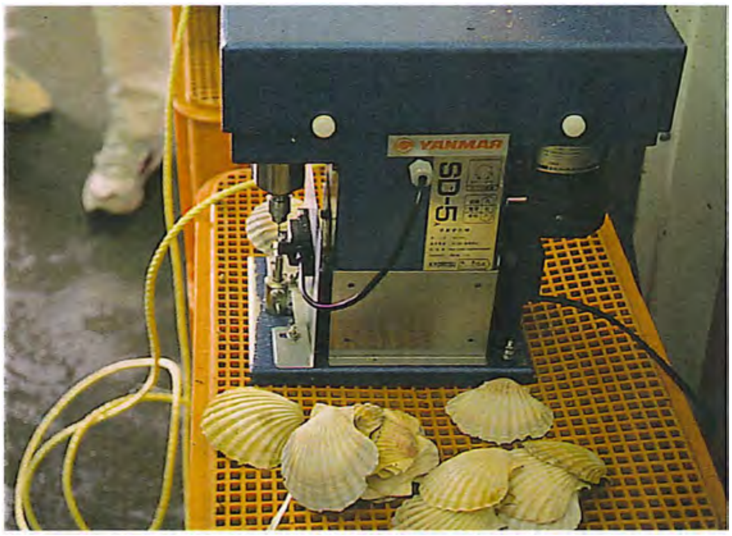

Figure 1.2 Ear hanging scallops (Pecten fumatus) at Triabunna, Tasmania

A recent development of this method, successfully tested by staff from N.S.W. Fisheries, involved gluing *Pecten fumatus* to a rigid plastic disc of the type typically used in lantern nets (Heasman *et al.* 1998, O'Connor *et al.* 1999). Results were favourable, with growth rates equal to or better than achieved with traditional earhanging. An advantage of being able to use smaller (30 mm scallops) was also reported. The cost of adhesives was considered to be a potentially limiting factor for commercial viability.

A similar method of attaching scallops to plastic tapes using marine epoxy glue was trialed in Scotland in the early 1990s (N.C.H Lake pers. com.).

All suspended culture systems use either longlines (more commonly) or rafts to support the nets or droppers.

In general, suspended culture is considered to give better growth rates than bottom culture (Mottet 1979, Bourne *et al.* 1989, Dadswell & Parsons 1995), although several recent studies comparing suspended and bottom culture have reported contradictory results (see below). Growth tends to be reduced with scallop density and depth in suspended culture operations, probably due to food availability (Parsons & Dadswell 1992, Cote *et al.* 1993, 1994, Emerson *et al.* 1994, Thorarinsdottir 1994, Maeda-Martinez *et al.* 1997, Lodeiros *et al.* 1998, Roman *et al.* 1999). Survival may also be influenced by depth, although not in a consistent manner, with lowest mortality generally being reported from intermediate depths (Lodeiros *et al.* 1998, Roman *et al.* 1999).

There are some problems associated with suspended culture systems, the most significant being fouling (Claereboudt *et al.* 1994, Lodeiros & Himmelman 1996). Fouling can affect scallops directly, by growth on the shell itself, or indirectly, by reducing water flow through the nets, which is required for both food and oxygen delivery. Fouling can also affect culture gear, making harvest difficult and requiring cleaning or re-buoying of the line. In extreme cases the weight of fouling can sink culture gear or result in loss due to breakage.

Fouling and stocking density present the largest problems in hanging cage culture and the solution is generally to change or clean nets and redistribute scallops at lower densities. This is both labour intensive and is considered to be a stressor on scallops. Net changes should be minimised for these reasons (Ito 1991), although Claereboudt *et al.* (1994) reported better meat yields, but not significantly higher shell growth, in *Placopecten magellanicus* culture when nets were cleaned regularly. It seems likely that culture species, site, fouling type and other management factors will determine the frequency of net changes and this may be variable for different operations. Disposal of fouling organisms has the potential to be a point source of pollution.

Predation is generally less of a problem in hanging cage culture than bottom culture, as the nets are not directly in contact with the seafloor. However, settlement of predatory organisms as juveniles, which then grow up, on or in the hanging culture system can be significant (Freites *et al.* 2000a, Lodeiros & Himmelman 1996).

An economic modelling program has recently been developed for viability analysis of large-scale hanging culture. This includes and evaluates variables such as net changes, duration in each growout phase and marketing factors (Pelot & Cyrus 1999).

1.2.2 Bottom culture

Bottom culture is a relatively simpler growout technique requiring less management than suspended culture methods. It is more akin to aquaculture than simple harvesting and differs from sowing and harvest in that the area is closely defined, may involve some form of tenure and may also include some degree of stock management, in addition to use of aquaculture apparatus. In the earlier definition, ranching more properly involves use of hatchery-produced spat rather than wild-caught animals.

The basic principle involves taking spat of suitable size and placing them within protective enclosures, either as a principal growout technique, to provide initial protection from predators or for escape prevention.

Frietes et al. (2000b) compared three methods of bottom scallop culture for *Euvola (Pecten) ziczac*. These included use of 0.2 m walls as minimum demarcation, 1 m high corrals and full cage structures. Results indicated that escape was a highly significant factor in the simpler enclosures, preventing effective long-term monitoring. In addition, escape was an increasingly important factor over time in the corral structures, as scallops became more efficient swimmers as they grew. In the cage structures, escapement was not recorded, but survival was found to be lower than in corral treatments.

The scallop *Argopecten ventricosus*, also studied in bottom-cage enclosure systems in Mexico, showed faster growth than scallops held in suspended systems (Maeda-Martinez *et al.* 2000) (See Section 3.8). Velez *et al.* (1995) also reported better growth in caged bottom culture than in hanging cage culture suggesting that stress reduction (through recessing) and supplementary food derived from bottom sediments were important factors. These results are interesting, as they contradict the widespread belief that suspended culture gives improved growth. These results may be relevant to oligotrophic tropical waters that may limit food availability in mid-water. Kleinmann *et al.* (1996) also obtained favourable results with the temperate species *Placopecten magellanicus* when comparing bottom and suspended culture techniques. In this instance, however, it appears that characteristics of the growout site are also an important variable in determining the better production system.

Bottom cage culture has also been attempted in Florida (see Section 3.12) and in Virginia with good results (Oesterling & Du Paul 1993).

1.2.3 Marine ranching and enhancement

The basic principles of marine ranching and enhancement (sometimes referred to as sowing and harvest) are dealt with comprehensively under the sections on New Zealand (Section 3.9, Section 4) and Japan (Section 3.6). In summary, the procedure consists of spat collection (usually from the wild, but potentially using hatchery-reared spat), sometimes with an intermediate suspended growout period to increase size before release, followed by deployment on a designated area of suitable seabed, which may or may not have undergone some form of preparation. If conducted on a larger scale and on traditionally productive fishing grounds it may be considered to be enhancement.

Harvest typically involves use of traditional fishery capture methods, usually a dredge, but potentially trawl gear, dependent on species. Harvest operations in Mexico and Chile are sometimes dive-based. The successful scallop production industries and programs in Japan and New Zealand are the best examples of this activity.

The principal advantage of this procedure is the relatively low cost. While an intermediate culture phase (to increase scallop size before sowing) may be needed, costs are generally less than those associated with alternative seed source and growout procedures, such as hatchery-reared animals and/or hanging cage culture. Spat collection, spat deployment and final harvest are the main costs, with limited outlay for growout.

The principal influences on successful bottom marine ranching and enhancement include:

- relative vulnerability of scallops to predation (either size-related or absence of protection from predators);
- suitability of the site for productivity (growth and survival) and harvest;
- dispersion from the seeding site.

Depending on combinations of these factors, in addition to natural mortality expected from sowing juvenile scallops, the numbers of spat required to obtain a commercially viable harvest can be considerable. Up to 2.5 billion spat were deployed in the early 1990s in individual Japanese regional operations (Ito 1991), and the New Zealand Challenger operation has deployed up to one billion spat annually (Fleury *et al.* 1997).

In part, these considerable numbers explain the general reliance on, and requirement for, wild-collected spat offsetting the alternative cost of hatchery production, labour and handling. However, regardless of spat source, maximising survival and subsequent recruitment to the harvestable stock will determine the success of the operation. Factors resulting in loss of seeded stock include predators, parasites, toxic plankton, physiological stress, pollution, unfavourable hydrology, poaching and bad weather (Fleury & Dao 1992).

Site selection has been suggested as being the most important factor for successful restocking (Fleury *et al.* 1997). Grall *et al.* (1996) reported the relationships between site characteristics and scallop density in order to determine the most appropriate areas for restocking of hatchery-reared *Pecten maximus*. It was found that high predator numbers, high competitor numbers (i.e. large epifaunal suspension feeders) or areas of high sedimentation rates were negatively associated with maintaining high scallop densities.

Predation is consistently reported as being an important factor in determining the success of scallop re-seeding operations (Lake *et al.* 1987, Halary *et al.* 1994, Norman & Ludgate 1995, Barbeau *et al.* 1998, Nadeau & Cliche 1998, Frietes *et al.* 2000).

Nadeau & Cliche (1998) conducted laboratory trials using two different sizes of *Placopecten magellanicus* (15–25 mm and 35 mm) and several species of crab and starfish.

Results indicated that crabs were greater and faster predators, but no clear preference was noted between the two sizes of scallops. The study concluded that sites with high predator densities should be avoided, and that re-seeding should be done with scallops >50 mm.

Barbeau & Scheibling (1994a) reported greater numbers of small scallops being taken by starfish in laboratory trials, although this was thought to relate to relative vulnerability, rather than size preferences as such. The situation with crabs appears more complicated, with generally larger sizes being taken. The preference for larger sizes appears to involve active selection, but also related to factors such as encounter rates and size-related vulnerability. In a similar study by the same workers (Barbeau & Scheibling 1994b), temperature was also found to affect predation rates of *P. magellanicus*, with higher temperatures (15°C) resulting in greater activity of crabs and starfish and, subsequently, higher scallop predation.

Barbeau *et al.* (1994) further developed their work in field trials, investigating the effect of scallop density and other variables on predation rates. Crab predation increased with scallop density, but starfish predation did not. In addition, water temperature and site characteristics also influenced crab predation rates. Starfish predation, as mentioned previously, was most influenced by water temperature and scallop size. Predators do not appear to be attracted to a site due to increased scallop densities from re-seeding (Barbeau *et al.* 1994, 1996); instead their individual predation rates increase.

The other main factor influencing restocking success relates to size at seeding, a factor frequently associated with predation and site characteristics. While larger-sized scallop generally survive seabed seeding better than smaller animals, site characteristics also influence survival. In a study using the Japanese scallop *Patinopecten (Mizuhopecten) yessoensis*, Silina (1994) reported that 15–16 mm scallops survived well at sites with aerated sand/mud sand sediments, protection from wave action and with high and stable salinities and temperature peaks below 18°C. By contrast, only scallops >19 mm survived at sites with finer-grained sediments or mud, and on sites with pebble-gravel-sand only scallops >22 mm survived. Recommendations included careful selection of site or increased sowing density to allow for losses.

Once a suitable site has been determined and seeded, the issue of monitoring the site becomes important, not only for management of the stock if appropriate, but also to estimate stocks approaching harvest.

Methods for monitoring scallop re-seeding sites have been reported by several authors, most utilising a combination of video and diving surveys (Cliche *et al.* 1994, Goshima and Fujiwara 1994, Fleury *et al.* 1996).

Cliche *et al.* (1994) reported significant dispersion of >60 m for almost 50% of re-seeded *Placopecten magellanicus*. Predation by crabs of up to 13% of scallops was also reported and dispersion was thought to relate to both the presence of predators and the initial high seeding density.

Hatcher *et al.* (1996) reported similar findings with the same species following monitoring over a 13-month period. Dispersion and predation were high during the first few weeks, with predation thought to have accounted for 50% of scallops. The loss rates decreased over the winter and spring months, but dispersion increased with warmer temperatures, to give a final density of $2/m^2$ (twice the natural maximum density) and 40% survival. The scallops used in this study ranged from 4–26 mm shell height, and mortality would appear to be rather high, based on previously reported work, particularly in relation to surviving predation. However, overall the study findings were positive, suggesting that mortality and dispersion were within economically acceptable limits.

In another study that monitored *Pecten maximus* survival and dispersion on re-seeding grounds, Fleury *et al.* (1996) reported a clear effect of seasonality in terms of re-seeding success. During autumn, apparently the worst period for release, 66% of smaller seeded scallops (15 mm) could not be found, although whether this was actual loss, dispersion, or recessing was not clear. This period correlated well with a low energy status in the scallops, which was linked to poor recovery following the stress of exposure, handling and seeding and a probable inability to recess. By contrast spring and summer appeared to offer the best periods for reducing re-seeding dispersion and survival.

Overall, therefore, there appear to be a variety of factors affecting scallop-re-seeding success. Using the variables of predation, dispersal and growth as inputs, Barbeau & Caswell (1999) developed a matrix model to predict survival of the scallop *Placopecten magellanicus* over time. An importance ranking was derived from this model that assisted the development of management strategies to maximise survival. Their assessment of the influence of management factors on survival, in decreasing order of effectiveness were reducing predator density, increasing seeded size, changing initial re-seeding density, increasing re-seeded area, altering re-seeding season.

Based on previous experience, both in Australia and overseas, and available published information the options for production of *Amusium balloti* and *Pecten fumatus* may be summarised as shown in Table 1.1.

Table 1.1 Summary of spat source and production options

	Wild-caught spat	Hatchery-produced spat	Suspended culture	Marine ranching and enhancement
Amusium balloti	✗	✓	?	✓
Pecten fumatus	✓	✓	✓	✓

2 Background: Scallops and scallop enhancement in Australia

2.1 Australian scallop fisheries

Scallops, members of the family Pectinidae, support major fisheries around the world. There are three identifiable scallop fisheries in Australia. Two, based on the saucer scallop *Amusium balloti* in waters off Queensland and Western Australia, have respectively generated average annual landings of about 1200 and 400 tonnes of meat annually over the past 10 years. Both have had considerable variation in landings, driven largely by years of abnormally high recruitment and production, but have consistently maintained production at, or above, long-term base levels of about 800 tonnes in Queensland and 300 tonnes in Western Australia. The southern Australian fishery for commercial scallops, *Pecten fumatus*, on the other hand, has declined in terms of production, value and social significance. The fishery peaked in the early 1980s, when production levels exceeded 3500 tonnes of meat annually, and has declined appreciably since that time (Dredge in press, Appendix 5). From being one of Victoria and Tasmania's major fisheries, the southern commercial scallop fishery now appears to be a peripheral operation for appropriately authorised commercial fishers.

2.2 Culture and enhancement – Tasmania

There has been considerable interest in culturing scallops for hanging cage culture or enhancement in Australia for some years. The Tasmanian government instigated a long-term program to examine the feasibility of developing cage culture and enhancement operations using both hatchery-reared and wild-caught commercial scallop spat in 1975. Dix and Sjardin (1975) reported successful rearing of larvae through to settlement, and their techniques were successfully applied to other scallop species (Dix 1976, Rose and Dix 1984). Spat collection rates in mesh bag collectors placed off the Tasmanian east coast were initially very low (Dix 1981, Hortle 1983), but improved with time and experience to reach up to 400 spat per collector (Hortle and Cropp 1987).

The Scallop Enhancement Research Project (SERP) was then initiated as a joint-venture agreement between the Tasmanian Department of Sea Fisheries (DSF) and the Japanese Overseas Fisheries Cooperative Foundation (OFCF) in 1986. Under this agreement, the Japanese organisation supplied technical expertise and capital for scallop mariculture, while the Tasmanian government provided research capacity, infrastructure, staff resources and an exclusive lease area of almost 20 000 hectares in, and adjacent to, the Great Oyster Bay. Thompson (1990) and O'Sullivan (2000) give brief accounts of the joint venture's progress.

The joint venture initially used open water spat-catching techniques to obtain spat, and followed the well established procedures of hanging cage culture for on-growing spat using intermediate culture techniques, as described by Ventilla (1982). The operations were not immediately successful and hatchery production was attempted for a short period before reverting to open water spat collection. Significant production of seed up to 30 mm shell height using intermediate growout was achieved in 1986. SERP used these scallops for re-seeding trials. Additional spat collection and re-seeding later occurred under the management of Tasmanian Scallops Pty Ltd. Spat numbers ranged between 15 to 400 per bag, averaging 100. Spat were on-grown in the collector bags to a size of about 25 mm shell height, before being sorted, graded, cleaned and transferred to tiered lantern nets (Figure 2.1). Suspended culture techniques were shown to produce the most favourable growth rates. Short falls in spat supply and cage fouling were reported to be major constraints to growth and economic production of scallops.

Figure 2.1 Sorting spat from spatbags – Triabunna, Tasmania

The operation changed organisational structure and direction, being largely taken over by a Japanese consortium and moving towards an open water marine ranching operation. In 1990, 6 million 15 mm spat were released and, in 1992, the first harvest occurred with a reported 90% recovery rate. This heralded a peak of expectation and activity in Tasmanian scallop restocking, with more than 130 people being employed (O'Sullivan 2000). Between 1991 and 1993, 50 million spat were released, but despite good intermediate assessments, the scallops disappeared prior to harvest. The reason for this has not been fully explained, although predation has been proposed despite a lack of evidence, such as empty shells.

Overall, commercial scallop production still appears to be potentially viable even though the venture has scaled back significantly from the early 1990s. The operation has supplemented cultured product with wild-caught commercial scallops, thus enabling more consistent supply and new marketing options. The operation has also made use of hatchery-produced spat from a commercial hatchery at Bicheno in order to reduce variation in supply of wild spat. Despite this, annual production has not exceeded 50 tonnes (Crawford pers. com.). Significant issues which may affect long-term commercial viability include high labour costs and fouling problems associated with suspended culture techniques, in addition to the relatively long growout time which tends to compound these problems. Following further restructure, the operating company is now re-directing efforts towards hanging cage culture, and is investigating the feasibility of mariculture for other molluscan species, as spat supply continues to be a limiting factor for commercial scallop culture.

2.3 Culture and enhancement in Victoria, New South Wales and South Australia

Mercer (pers. com.) has undertaken some early work on commercial scallop culture, based on pilot spat catching and cage culture, in Port Phillip Bay. This follows a more extended spat-monitoring program aimed at predicting recruitment levels in the wild fishery, reported by Coleman (1998). Mercer obtained good spat numbers in spat bags set in specific areas of Port Phillip Bay, and there is local interest and (as yet uncommitted) infrastructure for developing commercial scallop cage culture operations.

Commercial scallops intermittently settle in large numbers along the southern coast of New South Wales. Short-lived fisheries in areas such as Jervis Bay (Fuentes 1994) have occurred as a consequence of these settlements. As a result there has been significant interest in the possibility of culture and stock enhancement in the area, largely driven by N.S.W. Fisheries Department, since the late 1980s.

Initial research indicated that natural spat fall was both low and variable (Fuentes *et al.* 1992) and that any significant culture or enhancement program would have to be based on hatchery production. Hatchery production and potential growout techniques were developed during a series of projects reported by Heasman *et al.* (1995) and Heasman *et al.* (1998).

Spat production techniques are now considered reliable and efficient, having provided more than four million spat between 1994 and 1998. A novel, successful suspended-growout technique was developed, based on gluing scallops to a dropper rope. Results from this process indicated growth performance equal to or better than established methods.

There has, however, been little progress towards the development of commercial hanging cage culture or marine ranching operation. An early (pilot) attempt to establish a bottom-seeding program was unsuccessful, with predators including crabs, rays and starfish causing substantial losses to the stocked-out population in very short periods. Predation rates were size dependent, with larger size conferring longer survival. Consequent recommendations related to limiting predation included experimental use of predator-proof cages and the assessment of biodegradable canopies as predator protection for initial seeding.

Concerns about the environmental consequences of dredging seeded scallops may limit the geographic extent of future restocking operations in southern states. The Victorian government, for example, closed the Port Phillip Bay scallop fishery in the mid-1990s as a consequence of pressure applied by the recreational fishing lobby. There appears to be substantial opposition to dredge-based fishing in New South Wales from conservation interests, and little likelihood of a dredge fishery being authorised in inshore waters of that State.

There have been two commercial attempts to develop commercial scallop culture operations in South Australian waters. Both occurred in the period between 1996 and 2000, and were based on the concept of using spat collected from open waters in hanging cage culture operations, in waters to the north of Kangaroo Island. Little has been documented about either operation, but the initial attempt was apparently terminated following two seasons of unacceptably low spat numbers being collected (C. Young, pers. com.). An attempt to revive this operation in the Gulf of St. Vincent was in an early stage of development at the time of writing.

2.4 Enhancement of *Amusium balloti* in Western Australia and Queensland

The saucer scallop *A. balloti* has important biological and economic characteristics. It grows faster than any other scallop, reaching a harvestable size of 90 mm shell height (S.H.) in 6–12 months. The adductor meat has a slightly lower water content than most other scallops, and a uniform white appearance. It is, consequently, much sought after in niche markets in South-East Asia, particularly Hong Kong, where it attracts premium prices, sometimes double those of the world's scallop meat prices (Hart 1994). The rapid growth rate and high market value of saucer scallops implies the species has inherent potential for mariculture and marine ranching operations. There has been some research but little commercial commitment to translate this potential to reality in Queensland, but rather more in Western Australia. The apparent absence of anything more than a transient byssal attachment in this species (Robins-Troeger and Dredge 1993, Cropp 1994) limits the scope for wild-spat collection. Consequentially any marine ranching or enhancement operation would be reliant on hatchery-reared spat unless highly specialised spat-catching procedures can be developed.

Rose *et al.* (1988) reported on initial attempts to develop hatchery techniques for breeding saucer scallops under controlled conditions, and Cropp (1992, 1994) attempted to expand on this work to develop an operational model for saucer scallop enhancement in Western Australian waters. While Cropp's work was not immediately productive in a commercial sense, there have been subsequent attempts to enhance saucer scallop populations using hatchery-reared spat. The Western Australian government has granted an exclusive-access seabed lease in coastal waters at about 28°30'S, north-west of Geraldton, and a private venture company has established a hatchery as part of a program to generate a commercial marine ranching operation (Joll pers. com.). There appears to be some scope for companies currently raising pearl oyster (*Pinctada maxima*) spat to diversify into saucer scallop spat production should the present program achieve commercial success.

The current project is based around the concept of evaluating whether hanging cage culture and/or marine ranching of saucer and/or commercial scallops is commercially viable and, if so, what procedures are required to develop operational culture or enhancement. This, in turn, involves identifying bottlenecks to the operation of an enhancement project, which would almost certainly include restrictions associated with environmental management and other government policy. The project was also required to develop the basis of business plans should marine ranching, enhancement or cage culture appear to be a viable option.

3 Literature search: Enhancement and culture experiences from other countries

3.1 Introduction

Interest in marine stock enhancement to stabilise or increase the populations of important fish or invertebrate fishery stocks in coastal waters has increased significantly in recent years (Leber 1999). Two features of the global fisheries industry have principally brought this about. The first is a plateau or decreases in production for most mature capture fisheries, and the second a development of aquaculture and associated hatchery techniques for the production of the juvenile stages required for enhancement.

This interest is well illustrated by the occurrence of the first comprehensive conference on the subject, *The First International Symposium on Stock Enhancement and Sea Ranching* (Howell, Mokness & Svåsand 1999).

Scallop and other bivalve enhancement or restocking programs have not attracted the same level of commitment or interest as finfish on a worldwide basis, despite the recognised tendency for scallop fisheries to fluctuate from year to year and the success of scallop enhancement operations in some countries. A number of factors contribute to this situation.

- Despite significant fluctuations relatively few scallop fisheries have failed completely, however, in some of those that have, restocking has been attempted.
- Scallops tend to be components of multi-species fisheries and, therefore, fishers have tended to switch to other species when stocks are low.
- Restocking programs are expensive and require considerable lead-in time.
- Restocking programs require significant cooperation between government and fishers, which is difficult to achieve unless the fishery is in crisis.
- Technologies for seed production have been absent.

However, where significant commitment to a restocking program has been forthcoming the results have been spectacular. Conversely, limited commitment by stakeholder groups, and, in some cases, adverse biological or environmental factors have resulted in limited success or failure.

The following examples from a number of countries that have attempted scallop marine ranching, enhancement and culture, covering a wide range of species and environments, provide an overview of the development of scallop enhancement and aquaculture programs worldwide. They include some specific data and details relevant to the development of any such operations in Australia.

3.2 Canada

Scallops are the basis of significant fisheries in the west coast province of British Columbia and the east coast provinces of Newfoundland, New Brunswick and Nova Scotia.

On the west coast, smaller fisheries are based on *Patinopecten caurinus*, *Crassodoma gigantea*, *Chlamys rubida* and *Chlamys hastata*, and the introduced Japanese species, *Patinopecten yessoensis*.

Limited wild-spat collection and slow growth rates have made the native species less attractive for culture operations in Western Canada and the exotic scallop *P. yessoensis* is the focus of marine ranching and enhancement programs. All spat for these operations are derived from hatcheries. Suspended culture appears to be an expensive option and most interest is focussed on marine ranching through seabed cultivation. However, five sites in British Columbia produce > 50 tonnes of *P. yessoensis* annually, using hanging cage culture techniques.

Island Scallop Ltd in British Columbia produces eight million *P. yessoensis* spat per year and has a seeding site of 375 ha, in a location having a depth range of 20–50 m, sandy substrates and a low starfish population. A seeding program of eight million spat per year on 1/3 of the lease site was proposed in 1997.

The company's multi-species facility, which produces a range of mollusc, crustacean and finfish juveniles, also offers some of the additional benefits of hatchery-produced spat, such as selection programs for growth, disease resistance and hybridisation. They have successfully crossed *P. caurinus* and *P. yessoensis* to produce a scallop that is more suited to culture under west-coast conditions.[1]

The principal east-coast species is *Placopecten magellanicus*, although *Argopecten irradians* has been introduced. *Placopecten magellanicus* supports a 20 000 tonne/annum fishery but variation in landings has lead to interest in stock enhancement from wild-collected spat. Canadian provincial governments have also attempted re-seeding trials for public fishing. Wild collection of this species can return hundreds to thousands of spat per collector and growout trials for enhancement operations of depleted grounds using these spat are now underway. However, wild spat collection for *P. magellanicus* has been variable and hatchery production techniques have also been developed, to capture the benefits of regular supply and the potential for genetic selection.

The Newfoundland Provincial Government developed a scallop hatchery for *P. magellanicus* in 1995. A private company runs this facility and links to the local scallop aquaculture industry and tertiary institutions for research programs. The hatchery is capable of producing up to 20 million spat per annum, which are currently supplied to the developing local aquaculture industry. Penney and Mills (2000) report on a project designed to supply live, hatchery-reared *P. magellanicus* to select markets in the U.S.A.

As the more expensive option for spat supply, hatchery production is perhaps more likely to remain as a specialised supply, e.g. selected or hybridised lines, or as back-up capacity in case of poor wild-spat collection. That capacity and technology is, however, being established and will be a significant benefit for the development of restocking and aquaculture operations.

Hanging cage culture operations in private waters using *P. magellanicus* occur in Nova Scotia (4 farms), New Brunswick (1 farm) and Newfoundland (4 fisherman's cooperatives). The introduced species *Argopecten irradians* is grown in hanging cage culture in Nova Scotia from hatchery-produced spat (Mountain Island Hatchery, Nova Scotia).

The various growout and re-seeding trials have been supported under several different government and industry programs. These include: OPEN (Ocean Production Enhancement Network) in Nova Scotia, New Brunswick and Quebec, REPERE *(Recherche sur le Petoncle à des fins d'Elevage et de Repeuplement (Quebec))* (Cliche, Vigneau & Giguere 1995) and a development program in Newfoundland (Fleury *et al.* 1997).

Enhancement programs are currently at relatively early stages, although there appear to be several under consideration. For example, in the Bay of Fundy, a northern extension of the Gulf of Maine, the local fishing association is looking at enhancement as a method for overcoming decreasing scallop catches. The association is working with public sector, fishing and aquaculture industry members, and research and conservation organisations to develop acceptable methodologies to address:

- the enhancement process and its organisation
- harvesting

[1] www.bcsupernet.com/users/islandscallops

- resource allocation (in a fishery with 300 scallop licences)
- ecological implications
- areas of R&D
- issues of potential conflict and negotiation
- education.

All of these issues have been identified as needing to be addressed to allow the development of enhancement in Australia. Three models for the management of scallop enhancement were considered in a 1998 conference. Options included: a completely voluntary structure operated by fishers, either individually or in cooperation; a company model, in which exclusive seabed rights are provided to some fishers (similar to New Zealand model); and a Community Management Board model (again with some similarities to New Zealand). Exclusive access without total fisher agreement or inclusion was considered to be unworkable, and the community management option was favoured. Further details are available in the conference report.[2]

3.3 Chile

Scallop production from Chilean fisheries between 1971 and 1987 showed the common feature of highly irregular recruitment, in this case strongly linked to ENSO phenomena (Piquimil *et al.* 1991). Serious attempts to develop a cage culture operation, using U.S. based funding, commenced in the late 1980s and has one of the interesting and relevant histories for scallop culture that we know of on a global scale. A U.S. based venture company (Cultivos Marinos Internacionales, CMI) received considerable Chilean government support to establish a scallop hanging cage culture operation based on *Argopecten purpuratus* (Wolff pers. com.) and commenced construction of a hatchery in 1988. The hatchery was functional within a year and the company was able to collect and process in excess of 200 tonnes of scallop meat a year by 1993. The venture company ran into financial and organisational problems in 1996, apparently as a consequence of problems in a sister company that was created to cultivate clams in the U.S. Hatchery production problems in 1994, possibly associated with the proximity of the hatchery to the growout site and associated disease transmission, were also reported to have contributed to the company's financial problems (Rheault 2001). The Chilean arm of the operation changed hands and is now owned by a Chilean consortium. The hatchery and growout operation has developed into a fully functional hanging cage culture operation (Figure 3.1) that is producing more than 1000 tonnes of meat a year and employs 600 staff (Rheault 2001, *www. aquanet.com/Resources/aqua/region /cmi. htm*). Growth of ascideans (*Cliona* sp.) and other organisms on drop lines and cages is reported to have been a substantial challenge to the cage culture operators (Lindbergh 1999).

Figure 3.1. Handling scallops in hanging cages – Chile.

[2] http://www.gulfofmaine.org/library/conferences/fnfa_042498.htm

Spat are reared in hatcheries and ongrown to a size of about 10 mm in spat bags, in open water rather than in onshore nursery ponds before being transferred to cages for growout. Scallops are harvested at a size of about 80 mm, at eighteen months of age. The bulk of production is exported to the U.S. and Europe. The success of this operation has lead to emulation, and a number of smaller companies are now producing about the same amount of scallop as CMI, with total national scallop production exceeding 16 000 tonnes of whole scallop in 1998 (Lindbergh 1998).

There has been considerable spin-off from the culture operation, in that spat that has settled on culture cages and dropped to the seabed has created a *de facto* enhancement operation that is now supporting a fishery. Production based upon conventional fisheries techniques has increased appreciably and has been stabilised (Bustamante pers. com.).

3.4 China

China has generally responded to declining fish stocks and production in a consistent fashion, by readily and rapidly embracing aquaculture as an alternative production method.

China's wild scallop fisheries peaked in the 1950s at around 60 tonnes of dry meats but began to decline shortly afterwards due to overfishing. Experimental raft culture began in the early 1960s, but by 1979 the total Chinese scallop production was still only five tonnes of fresh meat from all sources (Lou 1991). Scallop culture increased rapidly in the early 1980s as spat production techniques were developed, and by 1985 production exceeded 10 000 tonnes. By 1988 total aquaculture production of scallops surpassed wild fishery production for the first time, and by 1996 was 31% higher at 31 million tonnes. Aquaculture production of scallops, which started only about 20 years ago, was estimated at one million tonnes (whole weight) in 1996 (Guo *et al.* 1999) (Figure 3.2).

Figure 3.2 Chinese long lines used for scallop culture. Photographer: H. Yang, in: Guo, X., Ford, S.E. and Zhang, F. (1999) Molluscan Aquaculture in China. J. Shellfish Res. 18(1): 19-31

The principal species are the native *Chlamys farreri* (75–80% of the total) and the exotic *Argopecten irradians* (20%). A small quantity of *Patinopecten yessoensis* (introduced from Japan) is grown in the north of the country, and the native *Chlamys nobilis* is grown in the south.

Spat production of *Chlamys farreri*, originally hatchery based, is now predominantly based on open-water collection, presumably enhanced through self-recruitment from the large numbers of cultured scallop. Quantities of 130 billion spat have been reported from a single bay. Spat are removed from collectors at 10 mm and sold into lantern net nursery culture operations. Growout, after reaching 25–30 mm, also occurs in longline-suspended lantern nets. Market size is reached after 19–20 months. Yang *et al.* (1999) report suppression of growth rates in cultured *C. farreri* as a consequence of overcrowding and raise concerns about potential genetic constraints associated with the massive population increase of cultured *C. farreri.*

There has been no apparent attempt to restock wild scallop beds on account of the relatively high costs involved in wild capture compared with the economies of scale developed by the large-scale aquaculture operations.

The principal problems encountered with the aquaculture operations include fouling, summer mortality due to high temperatures, overstocking and poor water quality. There is also concern about loss of genetic diversity in some areas due to self-recruitment in the population that was originally derived from a limited number of hatchery broodstock.

Argopecten irradians was introduced in 1982 from eastern USA with an initial stock of 26 animals, although subsequent introductions have occurred. Spat are exclusively hatchery produced and growout is again in suspended lantern net culture. Growth to market size takes one year.

Problems associated with this species are broadly similar to *C. farreri*, with genetic inbreeding concerns being paramount.

3.5 France

The principal commercial scallop species in France is *Pecten maximus*, which supports a significant fishery along the English Channel and northern Atlantic coast. A full review of French scallop fisheries was provided by Ansell *et al.* (1991).

As with many scallop fisheries, overexploitation has caused a significant decline in landings, particularly during the 1980s, which saw a 90% reduction in the fishery's production and indications of recruitment overfishing. Considerable research into restocking and enhancement has been carried out since that time, largely as a consequence of this decline.

Stock enhancement began in 1980 as a collaboration between IFREMER and local fishing organisations (Halary *et al.* 1994), in the Bay of Saint-Brieuc in Brittany. Re-seeding trials on existing scallop grounds were conducted using hatchery-produced spat that were given a period of intermediate culture. The first recaptures began in 1986, yielding up to 25% of the initial stock, which was lower than expected based on earlier surveys. As a result, a larger trial involving the seeding out of 3.1 million, 3 mm scallop in an area of 110 ha, from which commercial fishing vessels were totally excluded, commenced in 1990. Early results showed low mortality of re-seeded scallops but with a seasonal component dependent on time of release. Mortality was higher from the winter release, explained partly by predation by the whelk, *Buccinum undatum.* Crab predation was not considered significant. Release between spring and autumn gave mortality rates of between 15 and 25%. Smaller scallops were more susceptible to predation than larger scallops. There was notable spatial competition from the mollusc *Crepidula fornicata*, which can reach densities of 20 kg/m^2 and cover up to 20% of available seabed area, significantly reducing growth rates and affecting scallop recapture. Overall, survival rates coupled with appropriate selection of release period indicated that enhancement should be viable.

A similar, 10-year scallop enhancement program was established in 1983 in the Bay of Brest (Dao *et al.* 1994). Just over one million 25–30 mm scallops were seeded in two areas, of 50 and 200 ha between May 1989 and April 1990. Seeding density was 1/m^2. These areas were fished between November 1991 and February 1992, yielding 40 tonnes of scallops, which represented approximately 40–50% of the capture from natural beds in the area. The recapture rate of restocked scallop by fishing vessels was estimated at almost

21%, with a further 6% being left after the fishing season had ended. Survival from seeding during operations between 1989 and 1990 was estimated at between 4.7–36.5%, varying again with the time of seeding and also with the re-seeding site. While these results were regarded as encouraging, an improvement of the whole operation, particularly in relation to the variable survival rates, was expected with improved stock management methods.

An economic analysis of the French scallop production system was carried out at the completion of the 10-year program (Paquotte & Fleury 1994). Firstly, the production system, from hatchery through to harvest was defined, and all output targets, costs and requirements were detailed enabling the development of a model. Then, inputs or outputs were varied to analyse the economic feasibility of different scenarios using a project analysis program. This process appears similar to that undertaken during the current project (FRDC 2000/190).

In summary, the model indicated a good profit potential, although attention was directed to the issue of low initial income associated with the long growout phase, and improving recapture rates. In general, a survival rate of 30% after sowing is required for economic viability with an ex-farm price of 20FF/kg (approx US$3.50 at time of original writing). This price appears very conservative, on the basis of our experience of world scallop markets. The figure also corresponds to that reported by Japanese operations for economic viability (Ventilla 1982).

More recently, results from the same Bay of Brest area seeded with hatchery-produced spat indicate that enhancement now provides 33–50% of the local scallop fishery's catch (Fleury *et al.* 1997).

3.6 Ireland

As is the case for most national fisheries addressed in this section, production from conventional Irish scallop fisheries has tended to decline. Consequently, interest in culture has increased.

The principal spat source continues to be wild collection, with intermittent hatchery production, supplemented by imports from Scotland, although these latter two options appear to be both unpredictable and irregular in terms of spat supply. The reliance on wild spat, which also undergoes natural fluctuation, appears to be an industry constraint, and some research directed at improving supply is under way. Specifically, the use of mesocosms, or floating ponds in the open sea, have been developed for spat production by industry and Cork University. Trial quantities of up to 200 000 spat have been produced (Fleury *et al.* 1997[3])

Seabed seeding trials of *Pecten maximus* using wild-caught spat has occurred since the early 1980s. Limited information on the success and value of these operations appears to be available, although Fleury *et al.* (1997) provides some background material.

As with many scallops with a long growout phase, the need for intermediate culture has been recognised. Stackable rigid plastic trays and oyster cages have been used for this purpose, with multiple units being deployed and attached to the seabed. The relative expense of this equipment seems to have adversely affected commercial viability.

Following intermediate culture, sowing of 32–40 mm scallops has been carried out in two operations in County Kerry at Valentia and Ventry. Results from this operation are not yet available. Another operation in Connemara (Galway), which has involved collaboration between local fishers, local government and IFREMER, has carried out several scallop seeding operations. The first attempts in 1991 were unsuccessful due to predation by crabs and starfish and a relatively high dispersal current of up to two knots.

[3] http://www.ucc.ie/research/adc/posters/posters5.html

Subsequent attempts at alternative sites with a different substrate and current characteristics were more successful and over 300 000 juveniles were seeded onto the seabed. Three months after sowing survival was estimated at 87%, but large-scale starfish predation the following month destroyed the whole population.

Later, in 1996, some re-seeding of natural fisheries was carried out in the counties of Kerry and Galway, which was accompanied by fishing restrictions on the grounds to enable stock to re-establish and spawn. Information on the results from these operations has been difficult to obtain, although a private company harvested eight tonnes of bottom-cultured scallop in 1996 in a similar operation.

Several private companies and fisherman's cooperatives have also carried out suspended culture trials based on Japanese techniques. These have included both pearl net and ear hanging techniques. Interestingly, the Japanese scallop *Patinopecten yessoensis* has been introduced to Ireland for use in suspended culture trials.

3.7 Japan

Japanese production is concentrated on the native species *Patinopecten yessoensis*. Scallop production was derived entirely from the wild fishery, which can be traced back to the eighteenth century, until the early 1960s. During the 1950s and 1960s catches averaged about 11 000 tonnes per annum but were highly variable and trended downwards. Hanging culture techniques were introduced between 1969 and 1976 and production was boosted to average 57 000 tonnes per year over the period. By 1976 the actual production from all methods was over 95 000 tonnes (Ito 1991). Enhancement and hanging cage techniques were further developed from 1977 onwards and helped boost production to over 213 000 tonnes by 1983 (Figure 3.3).

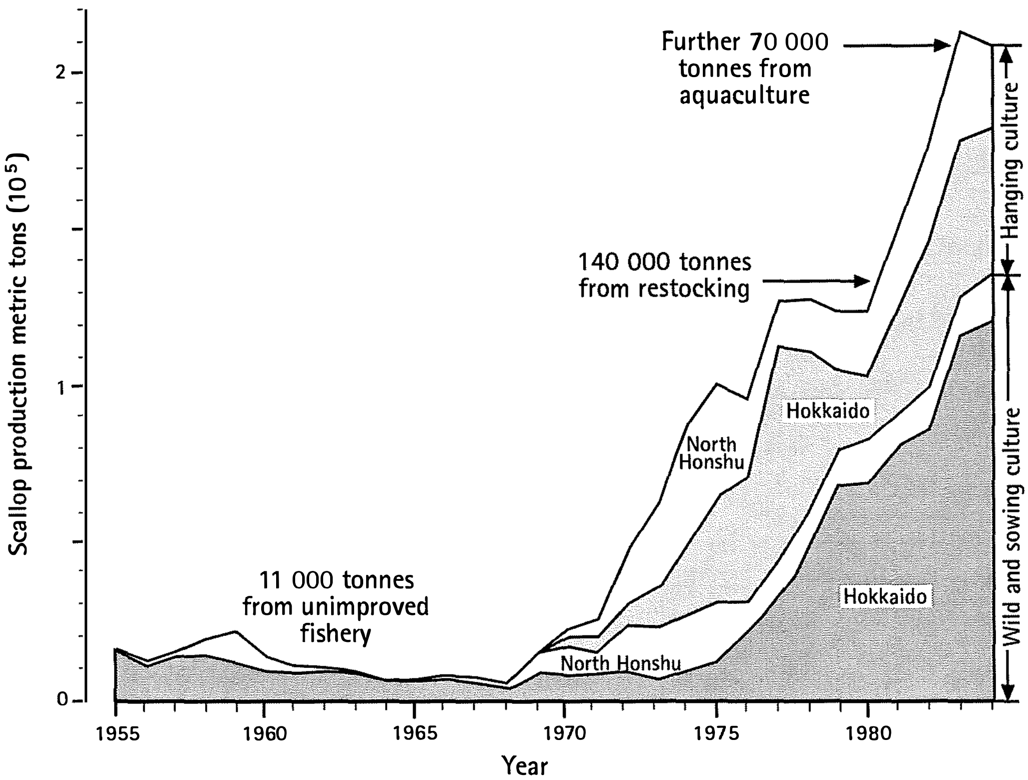

Figure 3.3 Annual Japanese scallop production from suspended, wild and sowing culture methods between 1955–84 (modified from Ito1991)

By 1990, total production, which was equally divided between various forms of suspended culture and bottom production techniques, was 400 000 tonnes (Ito & Byakuno 1990).

This summarises the remarkable history of Japanese scallop production since 1968. Faced with a declining wild-harvest fishery, the combined development of suspended aquaculture and seabed re-seeding has boosted production by a factor of 40, with similar increases in production value.

Scallop culture techniques, using elementary spat-catching systems and growout in suspended pearl nets, were originally developed in the 1950s, but without an effective spat production/collection method, the industry remained very small. The development of the simple spat collection bag in the mid-1960s, subsequently copied throughout the world, removed the bottleneck of spat supply and enabled rapid expansion of suspended culture and re-seeding.

The production increase continued until the mid-1970s when overstocking, particularly in hanging cage culture, resulted in shell distortion and mass mortalities (Ito & Byakuno 1990). Toxic algae blooms were also thought to contribute to these mortalities. Conversion to bottom culture (enhancement) followed, and brought about another significant increase in production from that method (Figure 3.3). In more recent times production from both methods has been largely equivalent, and the valuable lessons about appropriate stocking densities have been implemented (Ventilla 1982).

Japanese scallop culture and enhancement is predominantly carried out around the northern island of Hokkaido, the northern part of Honshu Island and in Mutsu Bay. Growout takes the form of suspended culture, using either lantern net or ear hanging techniques, or enhancement. The actual production method chosen is dependent upon the area, with hanging cage culture being largely independent of hydrography, but successful enhancement areas are heavily influenced by water depth, shore profile, currents and substrate type. One form may predominate in an area over another, although total production is similar from both methods.

Culture operations tend to be based on cooperative systems, with producers having fishing rights to discrete areas of sea floor or water. This structure also extends to spat production, with individuals of the cooperative expected to contribute a certain proportion of the total spat production used for subsequent growout (Ventilla 1982).

Descriptions of spat collection and culture techniques are given in Ventilla (1982) and Ito (1991). Spat production is entirely based on open water collection, largely due to lower cost and high natural abundance. This abundance is a consequence of the contribution made by large numbers of (spawning) adults in culture. Intermediate culture is undertaken for one year, using suspended pearl or lantern nets, to rapidly produce scallops of30–50 mm that survive better and are more resilient during subsequent growout. Intermediate culture provides good water flow for fast growth and affords protection from predators while spat are small. Survival during intermediate culture is up to 90% (Ventilla 1982).

Growout in suspended culture takes the form of either ear hanging, which requires scallops large enough to survive shell drilling, or lantern and pocket net culture. The latter are less favoured due to cost and the need for net cleaning (Ito 1991).

Enhancement operations also utilise the larger scallops produced through intermediate culture. Early attempts at re-seeding culture using 6–8 mm spat were largely unsuccessful due to poor survival. Size at release was, therefore, considered to be an important factor, with larger scallops being better able to tolerate the stress of re-seeding and survive predation. Consequently, spat for re-seeding undergo intermediate suspended culture to a size of around 30 mm, which provides a survival rate of 30–40% when sown at densities of 5–6m^2 (Ito & Byakuno 1990). Juvenile scallops are seeded following preparation of the seabed site, which principally involves predator clearing, particularly of starfish, which are removed by dredge.

The number of scallops required for stock enhancement is massive. For example annual seed input in Hokkaido in the early 1990s was 2.5 billion shells (Ito 1990).

Due to the relatively large initial size of sowed scallops, survival is around 30–40% after 3–4 years and, with recapture rates of about 80%, the overall recovery of seeded scallops is about 20–30% (Ventilla 1982, Ito & Byakuno 1990).

Improvement can be made, however, with refinement of site selection and preparation, predator control, handling and management. In Tokoro, for example, early re-seeding attempts without ground preparation were fairly unsuccessful despite the release of large numbers of spat. A more coordinated approach applied since the mid-1970s, with division of areas (25–30km^2) for sequential harvesting, regular spat supply, predator clearing and managed harvest resulting in a recapture rate consistently around 50% of initially seeded stock.

Several general points can be made about the Japanese experience.

- Seabed culture and enhancement can provide a large, low cost supply of scallops.
- Catch is proportional to the number of seeded juveniles and improves with management.
- There is a significant secondary effect on natural recruitment.
- Overstocking can be an important issue, with significant mortalities recorded when total scallop biomass exceeded 1.5–2.5 kg /m^2 on the seabed.
- Stocking density issues are also equally important during intermediate and suspended growout culture, influencing both growth and survival rates.
- Sorting and handling spat or scallops need to be minimised and performed carefully.

3.8 Korea

Limited information is available in relation to Korean work on scallop aquaculture and enhancement, although the Kangnung Fisheries Hatchery is working on production and potential restocking of the sea scallop *Patinopecten yessoensis*[4].

3.9 Mexico

The principal commercial scallop species in Mexican waters include *Argopecten circularis, Pecten vogdesi* and *Lyropecten subnodosus.* Commercial scallop fisheries are relatively recent, having commenced only in the early 1970s. Total scallop fisheries landings and value were 4206 tonnes (whole weight), worth US$2.6million in 1987. Aquaculture has also been developed based on *A. circularis* since the mid-1970s and is based on typical longline culture methods. Felix-Pico (1991) reviewed scallop fisheries and aquaculture in Mexico.

While no restocking operations have been undertaken as yet, some work on bottom culture techniques has been conducted. Seabed enclosures are deployed and scallops are sown into them, and remain there until reaching market size after about 5-7 months. Average growth rates are around 6 mm/month at a density of 100 scallops per m^2, with survival of about 85%. Enclosed bottom culture appears promising, although extensive culture is still being evaluated. This may, however, be a less promising method, again due to the impact of predators (Chavez and Caceres 1992).

More recently, a large-scale, bottom-culture trial using *Argopecten circularis* has been successfully trialed in Magdelena Bay (Maeda-Martinez *et al.* 2000). Using hatchery produced and wild-caught spat, 20 000, 32 mm scallops were placed into mesh sleeves at a density of 200/m^2. The sleeves were 50 m long and 1 m wide and almost 450 were

[4] http://www.nfrda.re.kr/intro/organ/orf_1201_e.html

deployed over a six-month period. Scallops were harvested between 3–10 months after deployment and overall survival was 64%, with an average size of 56.2 mm. Over 19 tonnes of meat were harvested. Differences in growth rate, survival and meat yield were found between different sites, again indicating the importance of site selection in bottom culture operations.

3.10 New Zealand

Detailed information on the New Zealand scallop fishery and enhancement operation is presented in Section 4 of this report.

The fishery for *Pecten novaezelandiae* began in 1959, and has been largely concentrated along the north coast of South Island, in Golden and Tasman Bays (Figure 4.1). Peak landings of 10 000 tonnes were taken in 1975, but declines and fluctuations have occurred since then (see Figure 4.2).

Trials in the 1970s based on Japanese hanging culture methods indicated that this procedure was not economically viable, largely due to fouling, and bottom culture appeared a more favourable option. In the late 1970s and early 1980s very low catches triggered the need for feasibility trials on restocking and enhancement. The trials used wild-caught spat, with significant numbers being seeded in the late 1980s: 150 million in 1989–90, 500 million in 1990–91 and one billion in 1991–92.

Several models for spat seeding were trialed (Bull 1987) with direct release of wild-collected spat and natural release (provision of additional settlement material for improved spat settlement) being considered to be economically viable. Intermediate culture, as practiced in Japan was considered uneconomic in New Zealand.

Assumed survival rates for each method were 15% direct release, 30% for intermediate culture and 30–40% from natural release. Wild-collected spat and dredged juveniles taken from spat-catching sites (25–50 mm) are seeded onto predetermined areas at densities of 4–6m^2. The larger scallops are used in high-predator abundance areas. Seeded stocks now account for 40–50% of the fishery's landings, which were 670 tonnes meat weight in 1999.

As in Japan, management controls have brought considerable benefits to the fishery. Minimum size limits, controls on dredge number and size, boats and closed seasons, in addition to rotational fishery cycles on seeded areas have all been introduced. Predator control has not been formally practiced, although it is considered to be a significant cause of mortality in seeded scallops.

3.11 Norway

A Government report on the long-term strategy for Norwegian aquaculture identified the scallop *Pecten maximus* as one of the main candidate species for aquaculture development.

The present wild fishery is dominated by *Chlamys islandica* and in 1994–95 landed between 5060 and 6250 tonnes live weight. The potential of *P. maximus* culture has also been recognised and consequently the Norwegian Scallop Program was established in 1993–94 to develop a new aquaculture industry.

Hatchery production of spat (by the University of Bergen, supported by Austevoll Aquaculture Research Station) began in 1993 and resulted in 4.7 million spat in 1995. The hatchery was taken over by a private company with industry shareholders in 1996, but spat production subsequently decreased. A bottleneck in spat production was identified as the transfer of post larvae (2 mm) from hatchery to sea conditions (nursery culture). Spat were described as scallops between 5–15 mm in size.

Additional information on the Norwegian scallop programs can by found in Fleury *et al.* (1997).

3.12 Scotland

Scotland has been the base for a substantial scallop fishery, based upon *Pecten maximus* and *Chlamys opercularis,* since the 1930s (Ansell *et al.* 1991). Extension of the wild fishery to an aquaculture operation is far more recent, with the first commercial Several Orders, giving legal ownership of the natural or seeded stock in an area, being granted in February 1993. Previously, only research organisations had successfully obtained legal protection of bottom-cultured stock. This development increased interest in the conversion from suspended culture of *P. maximus* to bottom culture. There were reported to be 21 applications for Several Orders being assessed in 1997 (Fleury *et al.* 1997).

Spat production, principally for suspended culture operations, is currently based on wild collection. Two hatchery-based projects for spat production, the Orkney Water Test Centre (Government, SeaFish Industry Authority and Scallop Kings PLC joint venture) and the Fisheries Research Laboratory at Conwy (Wales) (U.K. Government funded, but recently closed down) were initiated for large-scale spat production, but progress to date has been slow.

In 1997 an investigation into the industry requirement for hatchery-based spat production was initiated, indicating that spat supply is one of the key industry issues.

There are no scallop culture operations within the UK outside Scotland, where the industry principally developed from the practices of scallop diver-fishermen collecting legal size or undersize scallops and retaining them on the seabed or in suspended culture until market conditions improved or market size was reached. Hardy (1981, 1992) provides full reviews of scallop diving and culture operations in Scotland.

Traditional Japanese techniques and materials were initially used for both *Aequipecten opercularis* and *Pecten maximus* culture, but were later modified to reduce costs. Research organisations, principally the Sea Fish Industry Authority (SFIA) Marine Farming Unit at Ardtoe, further developed techniques and trialed alternatives such as earhanging (Paul 1985, 1987, 1988). Take up by commercial operations has been relatively slow, and generally equipment costs for suspended culture and/or the problems associated with fouling have restricted culture operations to a fairly small-scale. The long growout period for *P. maximus* (up to 5 years) exacerbated these problems, with premium prices always directed towards clean, larger diver-caught scallops.

The single exception, in terms of scale of operation, is Scallop Kings Ltd, a commercial company that floated on the stock market around 1989 and developed a very large operation with large-scale projections of production up to 3 million scallops per year by 1995. However, the Scottish scallop aquaculture industry is still dominated by a large number of small producers, but with a few large companies producing most scallops.

More recently SFIA have been involved in the European Union funded program investigating the potential for seabed cultivation of scallops (Fleury *et al.* 1997), principally as a means of finding a lower cost alternative to suspended culture and opening up options for more producers.

The principal findings from this work, which involved France, Ireland, Norway and Scotland, are

- access and stock protection rights over the seabed area are essential
- choice of seabed site is important, specifically in relation to predation
- site preparation, which might include predator removal, should be considered

- juvenile seed status, specifically size at seeding and vitality is critical to success and a vigour/stress test should be developed to ensure seedling quality.

The study also recognised the lack of some significant information in relation to biology, ecology and aquaculture regulation, if seabed culture is to fulfil its potential. This would require long-term commitment by government and industry.

Recent government statistics indicate that scallop production from culture operations has varied between about 8 tonnes and 58 tonnes in the last 10 years, but the quantities are still very low with a value of between £60–80 000 (approx. $A150–200 000) from 15 tonnes in 1999[5].

Aquaculture production in 1999 was lower than previous years due to an increase in biotoxin levels from marine algal blooms. This resulted in significant spatial closures around both scallop aquaculture and commercial fishery areas. These biotoxin-related closures reduced landings in 1999 by around 13%, although in general terms production from traditional dredge fisheries for scallops has remained relatively consistent over recent years.

There appears, therefore, to have been little incentive for government to initiate or develop restocking programs, since both dredge and diver fisheries remain relatively productive, aquaculture remains at a very small scale, and the issues of algal blooms and biotoxins are of substantial concern.

3.13 U.S.A.

The principal scallop species that support commercial harvest in the U.S.A. are *Argopecten gibbus* (calico scallop), *Argopecten irradians* (bay scallop) (of which there are two principal subspecies, A. *irradians* and A. *concentricus*) and *Placopecten magellanicus* (sea scallop). The former species is limited to the sub-temperate and tropical coast, while *P. magellanicus* extends from Canada as far south as North Carolina and *A. irradians* is found along the entire East Coast.

They are all heavily exploited to the extent that production from at least some fisheries/ species fisheries is declining and variable, due either to over-fishing or disease and pollution impacts.

Maintaining sea scallop stocks and production has tended to be addressed through fisheries management[6], although aquaculture/ re-seeding is being proposed, though with much less commitment than in Canada. Likewise, the calico scallop fishery also appears to be managed through regulation rather than alternative enhancement strategies.

However, there has been significant effort directed towards stock replenishment and enhancement of the bay scallop in Florida, North Carolina, Massachusetts, New York and Connecticut (Morgan *et al.*, 1980; Tettelbach & Wenczel, 1993; Peterson *et al.*, 1996).

A quite extensive commercial fishery existed on Florida's west coast until the 1960s, but overfishing, followed by a decrease in water quality, resulted in significant reduction of broodstock, and populations have not recovered. Currently, there is no commercial scallop fishing allowed in Florida, and even recreational fisheries have been closed as a consequence of very low scallop numbers.

Recently, however, National and State fisheries organisations and universities have combined to develop a restocking program in which scallops are placed in protective seabed cages where it is hoped they will re-establish significant populations around the

[5] http://www.marlab.ac.uk/FRSpage/MLApage/MLA.html and http://www.marlab.ac.uk/PDF/Shellfish99.pdf

[6] www.nefmc.org/documents/scallop.htm

Tampa Bay area. Improved water quality has been a key factor in enabling such programs to be developed, with scallops and the seagrass beds on which they settle being considered to be good biological indicators for general marine environment quality.

Seeded scallop stock is hatchery produced and ongrown to suitable restocking size with between 200–400 scallops in each 1 m^2 cage. The cages are used to protect the animals from predation. To date 35 000 scallops have been re-seeded. The program's initial aims are to establish scallop populations sufficient to re-establish and maintain recreational fishing, which are recognised as having significant economic and tourism value for local areas. The long-term aim is for a return to commercial harvesting[7,8].

Further north, in Connecticut and Massachusetts, similar declines in bay scallop populations have occurred due to overfishing, pollution, habitat loss and increased predation. Populations are reported to be significantly below those associated with normal fluctuations and consequently restocking programs have been looked at as an alternative strategy to stabilise or increase the fisheries' production. Both commercial and recreational fisheries occur, although they are now at very low exploitation levels.

Several different strategies have been implemented.

At the simplest level, community-based operations involving schools, colleges and local residents and relatively low-tech captive spawning, ongrowing and resowing, coupled with education about habitat requirements, have helped to improve recreational scallop beds[9].

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[7] www.fmri.usf.edu/invert/scallops.htm

[8] Florida chapter of the American fisheries society
December, 1998,Volume 16 (3) Scallop culture update

The second harvest season for the Florida Sea Grant funded bay scallop (*Argopecten irradians*) culture project is drawing to a close. The final harvest occurred October 30 from the lease site located several miles into the Gulf of Mexico from the mouth of the Crystal River. Seed scallops grown at the University of South Florida were transplanted from the St. Petersburg hatchery to the lease site in early summer. The scallops were then grown out to market size (40–45 mm shell height) in cages located at the lease site. Growout requires about six months. Market-sized scallops were then delivered to select area restaurants for market testing in whole form.

This year, as well as during 1997, market-sized cultured bay scallops were provided at no cost to a very select group of white-table cloth restaurants in Inglis, Cedar Key, and Gainesville. Chefs were asked to prepare the product in any manner they wished, as long as the product was cooked and presented to the patron in whole form. Patrons who ordered the appetizer, entree, or side dish were then asked to complete a brief questionnaire that solicited opinions about this non-traditional seafood product. With few exceptions, most surveys indicated a high degree of satisfaction and a willingness to purchase the product again, although a number of respondents expressed initial trepidation at the thought of eating a whole scallop. This suggests that a latent market for whole bay scallops exists in north central Florida.

A final component of the study will be an assessment of the economic feasibility of the cultured process on a small, commercial scale. The analysis will consider several growout techniques and utilize information from existing markets in the northeast US, as well as Virginia where similar research has been conducted. Culturing bay scallops for the meat alone would likely not be economically feasible given the large volumes of imported scallop meats. Although the technology required to produce seed scallops is fairly standard (i.e. very similar to that utilized for hard clams), the most appropriate growout technology is under development. The market potential for a shell-stock, cultured bay scallop to be consumed whole is not fully understood.

Currently, commercial harvest and sale of wild, bay scallops is not allowed in Florida. However, similar regulations in the northeast US have been modified to allow the sale of cultured bay scallops. Bay scallop culture may eventually provide a means by which existing hard clam growers in Florida can diversify.

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[9] www.capecodonline.com/cctimes/archives/1997/oct97/10_31_97/scall3.1htm

At a higher level, commercial operators and tertiary institutions in Massachusetts have undertaken transplanted ranching of juvenile, wild-caught scallop in areas closed to fishing activity. Long-term monitoring of survival and growth of re-seeded stock, in addition to alternative growout techniques (e.g. pearl nets and cages) are proposed. Obtaining government and fishing industry agreement on the re-seeding site was a significant issue[10].

The most significant restocking program also occurred in Massachusetts from 1995 and involved Federal and State Government and commercial collaboration. The aim of the project was to seed up to 30 million, 30 mm scallops in coastal embayments in order to restore the scallop fisheries which declined by 80% between 1985 and 1993.

This operation was based on hatchery-reared spat, using established techniques, followed by growout to appropriate size using suspended culture systems. Re-seeding sites were determined based on the following criteria:

- Previous history of scallop productivity
- Suitable habitat for good growth and survival
- Few indigenous scallops
- Few predators
- Low levels of water turbulence or unfavourable climatic characteristics
- Additionally, local willingness to accept area closure and assist with monitoring.

Divers monitored initial re-seeding operations to examine habitat characteristics, scallop distribution and predator abundance. Survival, distribution and predation were recorded over several months. Results indicated improved survival for larger scallops[11].

An earlier attempt to utilise hatchery produced *A. irradians* to assess the feasibility of re-seeding inshore areas of Connecticut was reported by Morgan *et al.* (1980). Using relatively small numbers of spat (47 000 in four seeding operations), loss estimates of scallops through predation or dispersion were determined. Smaller scallops appeared to suffer heavy losses from predation, with 50% loss for ≤ 22 mm spat reported in less than one day. This rate of loss decreased with increasing size and the population half-life was ≥ 6 days for scallops ≥ 24 mm, with predation accounting for less loss of scallops than dispersion. In addition, the rate of loss was lower for scallops > 40 mm compared with those < 35 mm. Several predators were identified, including numerous crabs and several mollusc and echinoderm species that had a proportionally greater effect on smaller scallops.

As a final example, the bay scallop fishery off Long Island in New York State was largely destroyed following toxic algal blooms in the early 1980s. A major restocking program was implemented in 1986 to boost broodstock numbers and re-establish the scallop population. It was initially based on hatchery-reared spat, but later supplemented with wild-caught spat (Tettelbach & Wenczel 1993). By 1989, 25% of spat settlement was estimated to be derived from re-seeded stock, with 75% coming from surviving wild broodstock. Subsequent good recruitment was reported from the area, apparently derived from both natural and re-seeded broodstock sources. The effect of restocking appears to have assisted in re-establishing a depleted population.

[10] www.s-t.com/daily/07-97/07-07-97/b011o038.htm

[11] www.state.ma.us/dfwele/dmf/dmfnq495.htm

4. Study tour report: Developments in the southern New Zealand scallop fishery

One element in the 'Feasibility of Enhancement' project was a brief study tour of the scallop enhancement work being conducted in northern embayments of New Zealand's South Island.

A tour group of seven people (two processors, one mussel / scallop farmer, a fishing industry representative and government-employed biologists, fisheries managers and extension officers) from Queensland, Victoria and Western Australia visited the location of a substantial scallop enhancement operation located in New Zealand in October 2000, for five days. The operation is located in Tasman and Golden Bays on the northern face of New Zealand's South Island, and based from Nelson and Motueka (Figure 4.1). The study tour was aimed at informing participants about the technology, management and outcomes of a New Zealand scallop enhancement project that has been developed over the past 15 years.

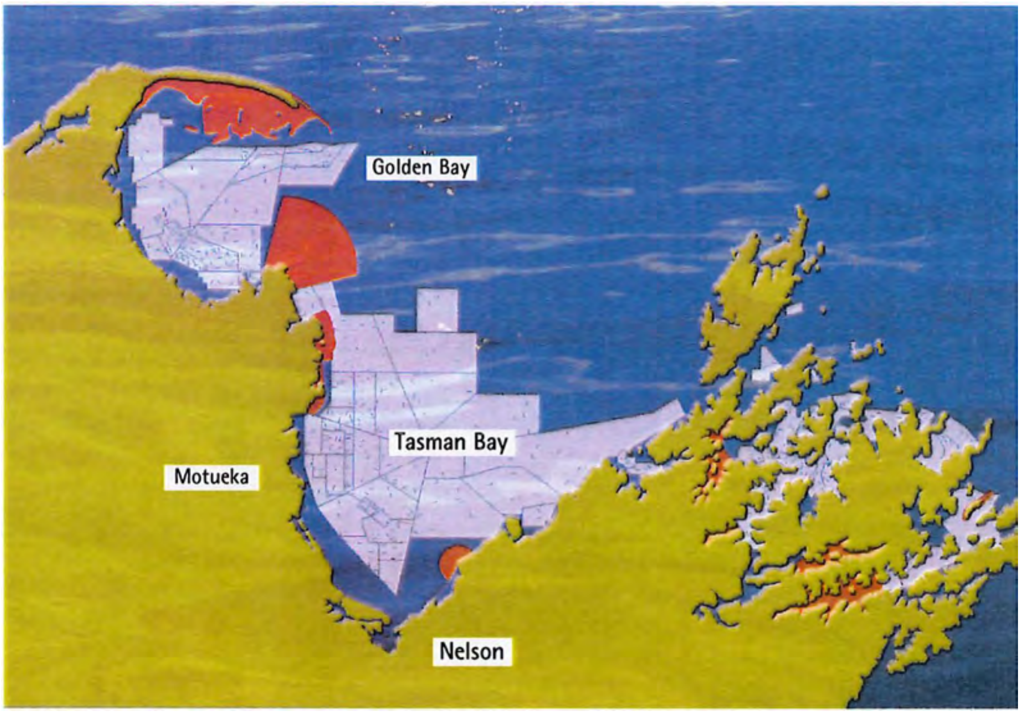


Figure 4.1 Golden and Tasman Bays, scallop enhancement locations

4.1 History

Attempts to enhance scallops (*Pecten novaezealandiae*) in the northern embayments of the South Island began in the mid 1980s. Previous to that, a scallop fishery of some magnitude had developed in Golden and Tasman Bays, initially as a byproduct from the local mussel fishery. Production from the fishery varied between zero and 10 000 tonnes (whole animal weight) (Figure 4.2, data from Bull 1990a, Arbuckle and Metzger 2000). The fishery suffered from the classic problem of almost all scallop fisheries – irregular recruitment. Consequently the fishery went through a series of boom and bust years, being closed down for two years in the early 1980s. Associated with irregular recruitment came the problem of overcapitalisation, when boat owners capitalised to take advantage of the good years, while having limited capacity to deal with those years when recruitment was poor.

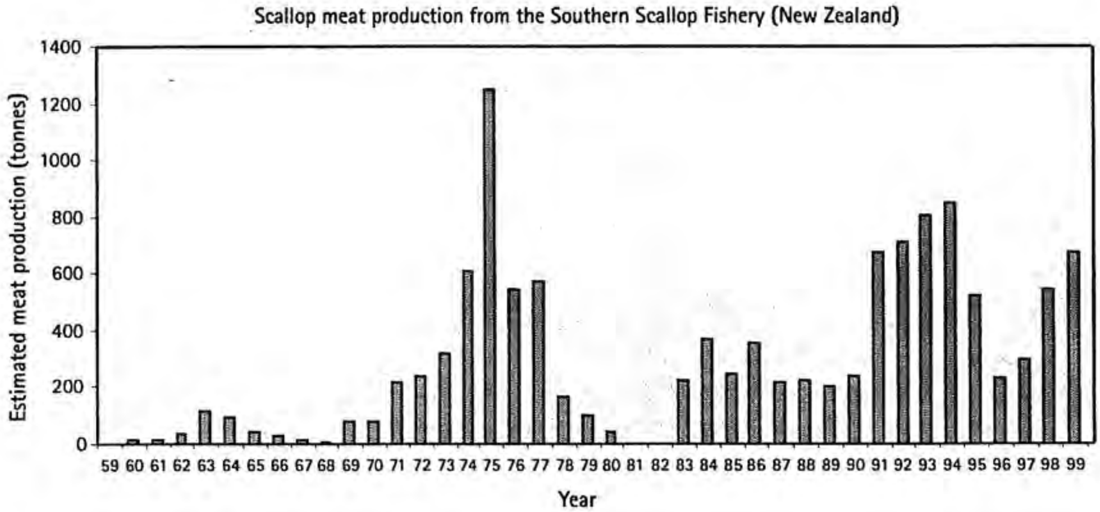


Figure 4.2 Historic scallop production – Golden and Tasman Bays

Managers and biologists began considering the use of Japanese technology and experience as a means of stabilising and enhancing scallop yields in the early to mid-1980s. A collaborative program between New Zealand's Marine Fisheries Management Agency and the Japanese Overseas Fisheries Foundation resulted in the placement of a Japanese scallop expert at Nelson. An extended research and development project, based on the concept of collecting spat from the wild, using spat bags, was conducted between 1985 and about 1990 (Clement and Bull 1988, Bull 1990b,1990c). The project examined the alternatives of ongrowing spat in hanging culture or direct re-seeding. Research staff concluded that direct re-seeding of 3 month old juveniles from spat bags offered greater potential for an economically viable enhancement project than using an intermediate culture phase (holding scallops in lantern cages to a size of 50–60 mm before re-seeding).

Certain physical and biological characteristics of the Golden Bay and Tasman Bay areas resulted in limited predation, high survival rates and rapid growth of seeded spat. In a process that was not fully investigated by the study tour group, the research and development phase translated to an operational commercial enhancement program over a 3–5 year period. This enhancement program and its associated fishery have production and management characteristics that are of considerable relevance and application to scallop enhancement operations in the Australian business and social environment.

4.2 Operational aspects

The enhancement operation is based on one of the *Pecten* genus' biological characteristics. All species of *Pecten* are broadcast spawners that have a 12–25 day larval phase. Post larvae settle on a range of substrates, and undergo a brief (1–3 month) byssal phase, during which they attach to the substrate or settlement medium by means of threads similar to those used by mussels. Following the byssal phase, juvenile scallops drop to the seabed where they remain relatively sedentary for the remainder of their lives. Scallop spat can be collected by inserting suitable substrates (coarse plastic mesh, old monofilament nylon, 25 mm gutter guard) inside mesh bags of 2–8 mm mesh and placing these bags in mid-water during and after the spawning season. Post larvae settle onto the inner substrate and grow to a size greater than that of the outer mesh before detaching. When they detach, they are retained in the outer bag, where they are protected from most natural predators. Growth of scallops held in spat bags is normally the same or faster than that of animals in natural habitats providing crowding is not too great. Spat so collected can be accumulated and released to create dense beds of individuals that can grow to a size large enough for harvest.

Alternatively, spat collected in spat bags can be transferred to hanging cages (pearl nets or lantern cages) for ongrowing, either to a larger size before re-seeding, or in a complete growout operation (Figure 4.3).

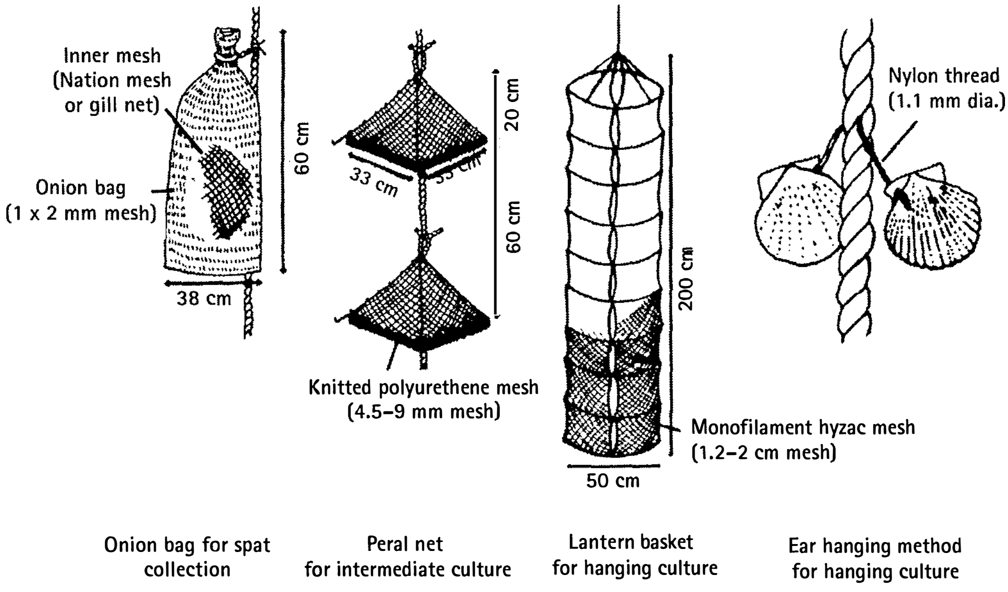


Figure 4.3 Spat collecting and growout equipment.

In the New Zealand enhancement operation, about 40–60 spat bags are set out on each of a series of vertical drop lines suspended from sub-surface longlines (Figure 4.4). These are typically set out just after the peak of the spawning season in November. The long lines are set taut and form the backbone between two main buoyed and anchored buoy lines.

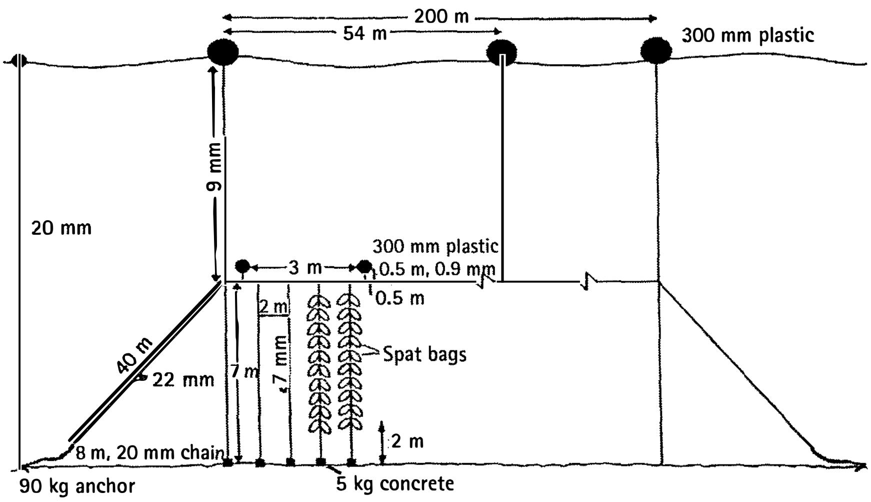


Figure 4.4 Scallop culture long lines

Appropriate location and set-timing of spat-catching equipment is a critical variable for a successful spat-catching operation. The lines need to be re-buoyed during the spat collection and growth phase to deal with fouling. The spat-bags are collected in about March, using a 20 m vessel purpose-built to handle the range of operations associated with enhancement. Specialised equipment is used to open the outer bags. Hand labour is then used to shake young scallops from the inner liner, wash them and transfer them to live holding facilities on board the vessel. The young scallops are then transported by smaller boats to predetermined seeding areas, where they are seeded at densities of about 5–7 /m^2. The operation is currently collecting about 400 million 10–20 mm spat for re-seeding, taking up to 2000 spat per spat-bag, but has the capacity to collect up to 1 000 000 000 spat if needed. The company responsible for re-seeding operations conducts a secondary seed-catching operation, in which they capture juveniles that settled on the outside of spat bags and associated equipment and drop off during harvest operations. Several million 20–60 mm scallops are taken by dredge in this operation, relocated to alternative areas and seeded out at densities that allow optimal survival and growth. Catch rates in this operation are high, with up to 20 million scallops being taken in a single day's fishing with two 2.2 m dredges (Figure 4.5).

Seeded scallops are allowed to grow to a size of 90 mm (shell height, minimum legal size) – normally 2 to 3 years – before being harvested.

Figure 4.5 Secondary scallop spat collection in Tasman Bay

4.3 The fishery and its management

The scallop fishery along the South Island's north coast appears to be unique in terms of management.

New Zealand's national fisheries legislation is directed towards maximising sustainable yield from fisheries resources. Government-administered ITQs are a mandatory management tool in all but exempt fisheries, of which there is only one at this time – the South Island's north coast scallop fishery. This fishery is managed under special provisions administered by a private company, the Challenger Scallop Enhancement Company.

The fishery has restricted entry, with 29 quota owners being entitled to take scallops commercially, or to lease out their quotas, typically to about 60 catching vessels. Share holding in the Challenger Scallop Enhancement Company is restricted to quota holders and the company is fully subscribed. Quota holders elect a board of governors, who oversee the company's operations and policy. The company, in turn, has terms of reference that include:

- developing business and management plans, and instigating civil contracts between quota holders and the company to ensure orderly harvest procedures that optimise economic returns to quota holders;
- administering and conducting enhancement operations;
- monitoring scallop abundance, size and condition;
- monitoring biotoxin levels in scallops within the managed area;
- developing scallop harvest strategies – seasons, areas to be fished , daily quotas and local management issues;
- supporting policing operations associated with the scallop fishery;
- dealing with strategic issues that might impinge on the viability of scallop fishing operations.

The management company also has responsibility for managing a small oyster fishery and is taking over the management of the north coast inshore scale fish fishery.

We were fortunate to be present on the fishery's opening day. Some 40–50 boats were fishing a bed created about a half hour's steaming time from Waitapu and were taking their $2\frac{1}{2}$ tonne (whole weight) daily quota in about six hours fishing time. They were fishing with two 2.2 m wide dredges of very simple construction, and fuel costs for the operation would have been minimal.

Figure 4.6 Fishing operations on enhanced scallop bed in Golden Bay

We estimated that the boats were fishing for about NZ$1500/hour. Scallops were held on deck before being unloaded and trucked to processing factories (Figures 4.6, 4.7).

The fishery is managed to optimise economic returns. Therefore, it is based on a short season so scallops are taken when in optimum condition. The management company regards the enhancement operation as being one of a number of key elements to its management program. Rotational harvesting is used to direct fishing effort towards areas where scallop size and abundance gives best returns to fishers, and away from areas where scallops are small.

In overall terms, the enhancement operation is providing in excess of 50% of the fishery's landings. There is some suggestion that natural spatfall levels are stabilising and increasing as scallop biomass and spawner levels increase through enhancement. Such a phenomenon has been observed in Mutsu Bay (Ito and Bykuno 1990).

Figure 4.7 Scallop landings from Golden Bay. Each boat was entitled to take 2½ tonnes of whole scallop (5 lift bags) per day, within an overall individual quota.

We were given the opportunity to see the full processing operation. The processing plant was a multi-purpose facility set up for scallop processing during the 12-week scallop season, then re-configured to process fish, vegetables or other primary produce that required value adding and freezing during the remainder of the year. The study tour's observations on procedures include

- large scale operations, with modern and well-maintained infrastructure.
- very heavy focus on quality control and hygiene in the factory – internal laundry, strict clothing requirements and obvious health precautions.
- very close tracking of individual boat / fisher's landings – for quality control, payment and to ensure compliance with quota requirements (Figure 4.8).
- high quality roe-on product aimed at export to Europe – individually IQF treated meats.
- very high labour content in processing operations.

Figure 4.8 Scallop shucking. Note bar-coded tag used to track each bag of scallops taken by fishers through processing and packing.

The study tour group was impressed by the Challenger Company's capacity to deal with strategic issues. There is, for example, a recreational dredge fishery for scallops in New Zealand. The Challenger operation not only allows recreation boats to work in the main scallop areas, but seeds 'recreational only' areas at no cost to the recreational fishers. This has enabled the previous bag limit of 36 scallops per person per day to be increased to 50 per day. The company appears to face few of the allocation and conflict issues between commercial and recreational sectors that bedevil Australian fisheries managers. In excess of 20% of the scallop quota has been allocated to Maori tribal interests. At a time of increasing litigation over the allocation of fisheries resources between indigenous and existing commercial fishers, we were advised that the scallop enhancement operation had no such problems.

We were also impressed with Challenger's financial management. The company currently operates on an annual budget of a little more than NZ$1.5m annually. This is obtained by levying quota holders, with payment being made on the basis of product taken through processing factories. The management budget represents something like 17½% of the fishery's gross wharf side value. Given the amount of infrastructure and expertise required for enhancement work, monitoring of both scallop and biotoxins and general management issues, we felt that the operation was being run very efficiently.

The company does, however, face challenges. It is attempting to deal with potential expansion of the massive, aggressive and litigatious mussel farming industry into areas traditionally used for scallop fishing. An appreciable proportion of the company's budget is allocated to the legal processes required to deal with this threat.

The group was most impressed with the study tour. While the technology associated with the enhancement operation has limited relevance to re-seeding requirements for saucer scallops, the management and company structure were a revelation to all of us, and we benefited considerably by examining a successful operation that had been carefully and strategically planned.

4.4 Conclusions

While the study tour had direct relevance to any operation involving *Pecten fumatus*, certain aspects of the technology used by the Challenger Scallop Enhancement Company have little relevance to any marine ranching or enhancement procedures for saucer scallops in Queensland and Western Australia. The project team undertaking a feasibility study on enhancing saucer scallops in Queensland and Western Australian waters are of a mind that while enhancement appears to offer considerable economic benefits in local conditions, spat will have to come from a hatchery, at least in the early stages of enhancement.

There were, however, considerable benefits obtained from the study tour.

The first and foremost was for project team members to see, first hand, that a scallop enhancement operation could be viable and profitable. The extension from this observation is that if enhancement of *Pecten* in New Zealand could be profitable, there was considerable potential for enhancing Queensland and W.A. saucer scallops, as they grow to harvestable size in half the time of the New Zealand *Pecten* species, and have approximately twice the market value of *Pecten.*

The second was the opportunity to examine management structures under which an enhancement program could take place. Translating a concept into a profitable operation isn't going to be easy, and there are a number of operational procedures and business structures that could be used. We were given the opportunity to examine one that had been proved to be effective.

The study tour group was able to take a holistic look at an enhancement, harvesting and processing operation. To get a comprehensive snapshot of an industry in five days was largely unplanned, but we were fortunate enough to arrive at a time when harvesting operations were beginning, and secondary seed catching operations could be demonstrated. We were able to see the (shore-based) establishment required to set up spat-catching equipment, and see an entire process cycle.

Finally, learning about the management structure used to manage the scallop resources in Golden and Tasman Bays was one of the more exciting aspects of the study tour. The management structure is flexible, efficient, strategic and has very clear purpose and direction. It seems to have many of the benefits associated with private enterprise, while maintaining the long-term focus on sustainability normally associated with public-sector management of fisheries resources.

All in all, it was a very crowded, enjoyable and educational tour, for which we duly acknowledge and thank FRDC, who funded the trip, and the Challenger Scallop Enhancement Company, who hosted us with considerable generosity and enthusiasm.

5 Potential enhancement and culture methodologies, feasibility and benefits (*Amusium*)

5.1 Background

Effective scallop culture, marine ranching and enhancement is currently based on two general methods. One involves collecting spat, usually by deploying spat collection bags in appropriate areas of the sea, but sometimes by rearing spat in hatcheries, and rearing these spat through to harvest in hanging cages or on long lines. Alternatively, spat can be on-grown to a size of 10–30 mm in hatcheries, in collection bags or hanging cage culture (intermediate culture) and then directly re-seeded onto the seabed for subsequent recapture using conventional fishing methods.

The large bulk of China's 1.5 million tonne production is based upon hanging cage culture technology. Japanese scallop production is split between the two procedures, with production from the country's northern islands coming from bottom re-seeding, and from the central areas (predominantly in Mutsu Bay) being derived from hanging cage culture. The New Zealand operation referred to in Chapter 4 is based entirely on a bottom re-seeding (enhancement) process.

5.2 Operational procedures, operational and biotechnology bottlenecks (Objective 1)

5.2.1 Hanging cage culture

Hanging cage culture involves transfer of spat from a hatchery or spat collection bags to vertical nests of 4.5–9 mm rachel mesh lantern nets, typically at a density of 20–50 animals per net. Lantern nets are normally hung in vertical arrays of about 30, and set out on buoyed long lines (Figures 4.3, 4.4). The length and number of long lines will vary with the magnitude of the operation, but in Mutsu Bay an area of 50 000 hectares is set aside for a hanging cage culture operation that produces 25 000 tonnes (whole weight) of scallop annually (Aoyama 1989).

There are a number of technical and logistic difficulties associated with hanging cage culture being used to rear *Amusium balloti*. These include:

- probable high levels of cage fouling by algal growth and pollution problems associated with cleaning up such fouling;
- the very high labour demands required for cage culture (dealing with fouling, thinning out, changing nets, re-buoying long lines);
- difficult and expensive logistics associated with anchoring cages in the relatively exposed waters where *A. balloti* occurs naturally;
- probable opposition to the use of hanging cage culture by conservation interests;
- probable cutting of lantern cage mesh by the sharp leading edge of *A. balloti* shell resulting in constant maintenance and probable slowing of shell growth;
- observed reduced growth of *A. balloti* when held in hanging cage culture, during preliminary trials (Cropp pers. com.).

Some of these matters may be resolved through further technological development and research. Others, such as the reality of having conservation interests accept open water hanging cage culture in locations suited to *A. balloti* survival and growth, and dealing with fouling and pollution problems, have the potential to be time consuming whilst having no guarantees of reaching satisfactory resolution in the short term. There is scope for pilot work on cage culture but we believe there is little scope for commercial operations in the immediate future.

Given the limitations on time and resources associated with the project, the scope to investigate limitless options, and the existence of existing infrastructure to work with marine ranching, but not hanging cage culture, we felt there was little justification in persisting with attempts at evaluating the costs, benefits and feasibility of conducting hanging cage culture using *A. balloti* at this time.

5.2.2 Marine ranching or enhancement through bottom re-seeding

The alternative to hanging cage culture involves the creation of artificial beds of scallops by obtaining spat from the wild or a hatchery, on-growing them to a size at which natural mortality levels do not present a threat to the economic viability of the operation, and re-seeding them at high density for later recapture.

The remainder of the evaluation will be focused upon the concept of creating scallop beds for later harvest by conventional fishing techniques.

Spat supply

There have been two fairly extended attempts to collect *A. balloti* spat in Queensland waters using conventional spat catching technology (Sumpton *et al.* 1990, Robins-Troeger & Dredge 1993). Neither of these studies showed any appreciable retention of spat. Attempts to collect spat in Western Australian waters using conventional techniques were similarly unsuccessful (Joll pers. com.). Rose *et al.* (1988) and Cropp (1994) conducted early work on rearing *A. balloti* through larval phases to settlement. They suggested that while a byssal phase may occur, it is transitory and of short duration. Duncan and Wang (pers. com.) have found that a byssal phase may extend for upwards of four weeks, but the byssus is far more transitory than is the case for most scallop species. This implies settled spat may be too small and the byssus too weak for spat to be collected in conventional spatcatchers. While the work of Duncan and Wang raise questions about institutionalised beliefs on the nature of byssal phase, spat fall and early settlement phase for *A. balloti*, there is little prospect of collecting spat from the wild for enhancement purposes in the immediate future. Their work does, however, offer scope for further investigation on ways and means by which *Amusium* spp. spat might be collected from the wild and possibly opens avenues for handling small spat. They also demonstrate potential for extending the byssal phase in the species as knowledge of factors associated with this phase develops and improves.

However, it is clear to us that if an enhancement program based on *A. balloti* is to be developed in the short to medium term, it must be based upon hatchery-reared spat and an associated release process.

Hatchery rearing risks and bottlenecks

There has been some previous research on hatchery rearing of saucer scallops. Rose *et al.* (1988) described culture systems used to spawn and rear larvae through to settlement stage and Cropp (1992, 1994) gave further detail on larval rearing and described larval settlement and early juvenile growth. Wang and Duncan (pers. com) have reared saucer scallop spat through their post-byssal phases, and as of May 2001 were holding and working with an estimated 10 000 four month old (30–40 mm S.H.) animals. Their work suggests that rearing of scallops to a size appropriate for re-seeding is feasible.

Growth of this batch has been appreciably slower than would have been the case in the wild. We suspect that the current feeding regime and handling procedures may not be optimal. Further research on hatchery and nursery feeding procedures is required.

While spawning of *A. balloti* in a hatchery environment has become a routine procedure, rearing of larvae to settlement and beyond is very much an art form. Developing standardised procedures that enable large-scale culture of larvae and settled juveniles is possible, but further research and 'hands-on' rearing work is required to develop such standard procedures to a point where they can be documented and replicated. In particular, our understanding of nursery designs and configurations that minimise handling and labour costs while optimising growth and survival needs improvement.

An enhancement operation may require spat on a year round basis. Spat have thus far been artificially reared during the species' normal winter-spring spawning season. Work is required to identify cues that trigger gametogenesis, and also to condition saucer scallops for spawning throughout the year.

Transport phase

An enhancement or marine ranching operation based upon hatchery-reared scallops will require a transport phase, in which juveniles are transported from the hatchery to the growout site. While this seems to be a simple procedure, it has the potential to offer considerable logistic complexities when considered in the context of moving several million juveniles. Mercer (pers. com.) advises that juvenile Japanese scallops (*Patinopecten yeossoensis*) can be transported chilled (6°–9°C) and dry for upwards of 12 hours, with an obvious saving in transport cost. We attempted a trial run with juvenile (50–70 mm shell height) *A. balloti*, held dry but in humid (salt water air) conditions at 10–12°C for 8–10 hours. Mortality after transport, followed by two days rest in holding tanks, was 100%. It is obvious we will have to examine transport protocols for ensuring juvenile scallops are moved to re-seeding areas at minimal cost and maximum survival, but on early indications immersion-based methods will be used for transport.

Survival and growth of re-seeded scallop

Predation and survival of juvenile saucer scallops in a re-seeding operation is a potentially major threat to the viability of an enhancement operation. The experience of Heasman *et al.* (1998), in addition to overseas experience, suggests that small-scale pilot releases have little value – predators have to be saturated, controlled or temporarily excluded from stocked areas during the initial periods of re-seeding which may be for 3–4 months after settlement. Japanese re-seeding operations rely on predation controls, and the New Zealand enhancement operation referred to above also removes starfish from re-seeded beds on an ad-hoc basis. Survival of re-seeded scallops will be an obvious potential bottleneck to the success of an enhancement operation. There is considerable scope for extended work on survival and growth of hatchery-reared juveniles. Whether this should be done as an element of a research project or as part of a pilot project is open to question.

Identification of hatchery-reared scallops

Releasing hatchery-reared saucer scallops into an area suited to the species, and which may have previously have supported commercial densities of scallop, leads to a requirement that naturally settled animals be differentiated from hatchery-reared stock. Many of the conditions associated with an experimental aquaculture authority for scallop enhancement granted by Western Australia's Department of Fisheries (see Section 6) relate to this issue.

We do not believe that distinguishing between hatchery-reared and naturally spawned saucer scallops will present a major challenge. While relatively sophisticated techniques such as oxytetracycline, calcein and DNA micro-satellite markers may be used to 'tag' hatchery-reared scallops, the scallops may well self-tag anyway. Scallops are known to create very characteristic pigment flares and checks on the shell when substantial impact, such as being caught and sorted during fishing operations breaks the shell's leading edge (Joll 1988). We suspect that juvenile hatchery-reared scallops will acquire substantial check marks during the transport and re-seeding phase. Further, the trial group of hatchery-reared scallops referred to above had very characteristic colouration and growth patterns that were readily distinguishable from juveniles taken from the wild. While field trials may indicate otherwise, we believe that one or more of these simple forms of identification should prove adequate, and should be used unless they are found to be inadequate.

5.3 Social and biological risks associated with marine ranching and enhancement (Objective 2)

5.3.1 Social risks

Fisheries enhancement programs are obviously designed to improve social and economic welfare. We have conducted much of our modelling work around a marine ranching operation designed to generate approximately 100 tonnes of scallop meat annually (See Section 5.4, Appendix 3). Such a level of enhancement would represent a direct cash injection of approximately $2.5m into the regional economy involved, with an appreciable multiplier, given the level of infrastructure and labour required to support such an operation.

We identified four issues that could be identified as social risks.

The first was one of costs to non-participants in a marine ranching operation. A marine ranching operation requires an exclusive-access area to ensure those who risk the costs of the operation gain the benefits. It is possible, however, that an exclusive access area may impose costs by excluding fishers from areas that have been traditionally fished. Western Australia's Department of Fisheries has dealt with this issue by allocating an exclusive area in a location not traditionally open to trawling. This is not such an easy option in Queensland, where there has been an established history of allowing trawling in most available and suitable grounds. There are a number of options that could be considered in Queensland. They include:

- exclusive use of an area that has traditionally had irregular recruitment, but is not a major fishing ground;
- venturers in an enhancement operation offering some form of compensation to those who have lost historic access rights to an exclusive access area;
- internal agreement and acceptance by the industry as a whole that the value of information gained in the early stages of a marine ranching operation outweighs the cost of losing an exclusive access area.

We have introduced a cost component based on 'loss of access to existing fishers' in the benefit-cost models described in Section 5.4.

The second issue revolves around participation rights in a marine ranching operation. Potentially, a marine ranching venture could range between having a single venturer to being a cooperative activity involving an entire catching and processing component of a fishery, as in New Zealand, i.e. an enhancement program. Depending on the extent of entry criteria and the number of potential participants, decisions may have to be made about who participates and who doesn't. Decision rules could be based around:

- access being offered to all fishers and processors involved in the fishery: those prepared to take the initial financial risks of supporting the operation have access rights, on a pro-rata basis according to financial commitment;
- if a marine ranching operation bid is 'over-subscribed', access be given to those with traditional involvement in the fishery;
- access being on the basis of first come, first served, i.e. for government to deal with applications for a marine ranching venture reactively.

The third issue involves possible concentration of boats and processors in the immediate vicinity of an enhancement operation. This could, theoretically, lead to relocation of regional employment and capital. We believe that this is unlikely to be a real issue in the short to medium term, as vessels involved in scallop fisheries are highly mobile, and factories have existing infrastructure to deal with transport needs of scallops being caught and landed at ports that are distant to factories.

The final social costs or risks we can envisage in this process are the perceptions within conservation management agencies and lobby groups that marine ranching or enhancement will have an impact upon natural ecosystems. We have some reservations about the reality of this argument. Saucer scallop populations fluctuate in both numbers and geographic distribution from year to year. Creating a hatchery-reared bed at high density seems very little different to having such a bed settle naturally, and the consequences of having a natural bed in a given area would be almost identical to a created bed both areas would be fished heavily, with associated and similar impacts.

We have entered into initial correspondence with both the Great Barrier Reef Marine Park Authority (GBRMPA) and Queensland's Environmental Protection Agency (EPA) about the 'in principal' concept of scallop restocking in Queensland waters. GBRMPA's response was conservative and negative, whereas the response from EPA was much more positive and supportive. It appears that a scallop enhancement program, if undertaken in Queensland waters, will occur in waters to the south of the Great Barrier Reef Marine Park, but within the natural distribution of ***Amusium balloti***. Western Australia's Department of Fisheries has already issued an Aquaculture Licence seawards of Geraldton under that State's normal consultative processes with a range of interest groups, including the State's Environmental Protection Agency.

5.3.2 Biological risks associated with enhancement

We have considered biological risks in the context of Blankenship and Leber's (1997) 'Responsible Approach to Marine Stock Enhancement'. They identify ten key issues that must be addressed in order to meet basic standards of responsibility. These include a range of social, structural and biological matters.

These key issues include:

- prioritise and select target species
- *develop a species management plan*
- define quantitative measures of success
- *use genetic resource management*

- *use health and disease management*
- form enhancement objectives and tactics
- *identify hatchery-reared animals and assess stocking impacts*
- *use empirical processes to define optimum release strategies*
- identify economic and policy objectives
- use adaptive management.

Many of these issues have been addressed in other sections of this report. Those issues that may give rise to biological risk have been highlighted above, and will be addressed on an issue-by-issue basis.

Species management plan

The existing fisheries for saucer scallops are already managed under existing management plans and arrangements in both Western Australia and Queensland. In both fisheries, the stocks are monitored through both fishery-based data sets and fishery-independent surveys. Both management agencies treat the saucer scallop resources with caution. Queensland manages under formal decision rules and trigger points, and has set aside high-density areas of saucer scallop as broodstock reserves. The Western Australian fishery operates in such a way that the fishery closes when stock densities are fished down to a given level, determined by the economics of the fishery. This cut-off level is currently much higher than average catch rates in the Queensland fishery. While recruitment variation is a fact of life in these fisheries, they are managed in a precautionary manner and the risk of overfishing is minimal.

The proposed marine ranching operation we have evaluated is not designed as an alternative to management of the wild stock. It is proposed purely as a means of improving economic and social welfare by generating increased production.

Genetic protocols

One of the major issues associated with restocking programs is the potential for seeded animals to distort the existing genetic structure of the natural population. Should the re-seeded population be bred from a small number of parents, and /or the restocked population be large in proportion to the natural population, the risk of unplanned shifts in gene pools are greater. Unplanned shifts in genetic structure are more likely in situations where discrete stocks of a given species exist.

We envisage no such problems with unplanned genetic shifts when restocking saucer scallops. Sexually mature adults can be obtained readily in large numbers, and triggering animals to spawn in quite large numbers has never been a problem. Using a substantial and rotating parent stock does not present anything like the logistic problems associated with restocking large fish such as barramundi. Further, we envisage that restocked saucer scallops would be harvested in the summer and autumn of their first year of life, before becoming sexually mature. Few restocked saucer scallops would therefore contribute to the natural breeding population.

Preliminary work on the genetic composition of saucer scallops (Dredge et al. m/s, Keenan pers. com.) indicates that the Queensland saucer scallop population is a single genetic entity. The Western Australian population probably represents an as yet undescribed but distinct species. Structured stocks are unlikely to be a factor mitigating against an enhancement operation.

There could be interest in selective breeding or the use of parent stock with particular characteristics (fast growth, heavy adductor muscle) as an enhancement operation develops. We would caution against such a procedure, as we have no knowledge of the long-term consequences of undertaking selective releases into open water.

A genetic management protocol should be based upon the following procedures.

1. Introduction

The purpose of this protocol is to ensure that saucer scallops that are hatchery-reared and released to the wild as part of an enhancement or marine ranching operation are sourced and bred under procedures that minimise the risk of shifts in genetic structure of wild populations.

2. Broodstock collection

Records on the source locations, capture date and condition of broodstock should be collected and maintained for a three year period. All broodstock should be tagged, using procedures that allow individual identification.

3. Breeding procedures

Broodstock should be held and breed in batches of at least 30 animals. No single scallop should be allowed to act as the parent stock for more than a single batch of saucer scallops released into the wild, i.e. there should be a 100% turnover of broodstock for each major release event. Broodstock should be destroyed at the conclusion of each spawning and spat release.

4. Harvest procedures

Scallops sourced from a hatchery should, as a matter of practice, be harvested in the first summer or autumn of life, i.e. prior to their becoming sexually mature.

Disease protocols

Diseases that might specifically affect *A. balloti* are unknown. Any attempt to conduct an enhancement operation based upon release of hatchery-reared spat or juveniles that had not been subject to a macroscopic and microscopic examination against routine disease management procedures would be grossly deficient.

The following protocol is substantially based upon that recommended for mollusc hatcheries in Western Australia, and is largely based on a draft document developed by Brian Jones, for Western Australia's Department of Fisheries. Dr. Jones's generosity in allowing the use of this document is acknowledged.

1. Introduction

The purpose of this hatchery protocol is to ensure that any saucer scallops (*Amusium* spp.) spat produced within hatcheries is done so in a manner designed to reduce the risk of the disease transfer or introduction of non-endemic micro-species to wild scallop populations or other species.

All hatcheries authorised to produce saucer scallops (*Amusium* spp.) should be accredited by way of an annual inspection from a relevant State authority and through ongoing health certification. Each batch of spat produced within the hatchery will require an approved health certificate prior to its removal from the facility to a licensed growout site or other licensed facility.

2. General protocol for the translocation of saucer scallops

As a general principle, all saucer scallops required as broodstock for any hatchery should be sourced from stocks endemic to the proposed release area and in accordance with an approval granted by the relevant State authority.

Should broodstock be required for a hatchery and originate from an area outside the normal distribution of saucer scallops, the proponent should be required to apply to the relevant State authority for written authority to translocate the stock.

3. Minimum standards required for annual accreditation of a mollusc hatchery

a) The hatchery facility must be built to a reasonable standard and should incorporate security measures to prevent the entry of persons not authorised by the hatchery manager.

b) Authorised officers and/or persons competent and accredited as pathologists from relevant State authorities should have the right of entry to the property and facility for the purposes of annual inspection or at any other time deemed reasonable to ensure compliance with licence conditions.

c) Any unusually high mortalities or other signs of disease shall be reported to relevant State authorities within 24 hours of the event. In such an event, a sample of at least 60 affected live shellfish stock shall be immediately fixed in 10% formalin seawater and submitted to the fish health section of the relevant State authority for examination.

d) All entrances and exits to the hatchery facility should have footbaths installed containing 100ppm chlorine, or other disinfecting solution approved in writing by the relevant State authority. The chlorine solution in footbaths should be changed on a daily basis.

e) Water inlet and outlet pipes to the hatchery should be widely separated to obviate the risk of disease cross-infection. The minimum distance between inlet and outlet pipes has not been prescribed for the purposes of this document but should be as large as is practicable for each individual facility.

f) Live food production:

- Water used for the production of algal food for larvae, settled animals and broodstock should be either autoclaved; or filtered to 0.2μm.
- Air supplied to water used for algal larval food production must be filtered to 0.2μm using sterile filters.
- Equipment used for the production of algal food for larvae must be autoclaved or chemically disinfected between algal batches.

g) The hatchery must maintain a daily logbook of its general operations. This should include details of broodstock received by the hatchery and mechanical operations within the hatchery including any breakdowns.

h) The hatchery must maintain a daily logbook on each batch of larvae/spat. This should include details of:

- broodstock used to produce larvae/spat
- estimated numbers of larvae retained at each culling
- a regular record of size and stage of larvae
- a record of date of first and last day of settlement
- a record of estimated numbers of settled spat
- a record of estimated numbers at the time of sampling for the health certificate and
- any significant mortalities.

i) The hatchery operations logbook and the batch logbooks should be stored and maintained by the hatchery for at least three years and be available for inspection by authorised officers from the relevant State fisheries authorities.

j) The hatchery must maintain strict standards of hygiene (See notes on cleaning and disinfection, below). These include:

- All tanks should be thoroughly cleaned and disinfected after each batch of larvae or spat is removed and prior to new batches being placed in them.
- Hatchery personnel should institute, describe in writing, and maintain effective procedures to avoid cross-infections between different batches/species to the satisfaction of the relevant State fisheries authority.
- The hatchery should have adequate facilities to ensure that batches of spat from different species are kept physically separated for the purposes of disease control and compliance regulation.

k) Wastewater from hatcheries must be filtered through sand (equivalent to 20μm), treated with chlorine or be treated by some other method of wastewater disposal that has been approved by the relevant State fisheries authority.

General notes:

Accreditation of a mollusc hatchery must be renewed annually, subject to satisfactory inspection by an officer approved by the relevant State fisheries authority.

If any unaccountable mortalities or signs of clinical disease have been noted in either broodstock or spat, the accreditation of the hatchery may be suspended until the cause has been investigated to the satisfaction of persons competent and accredited as pathologists from relevant State authorities.

Hatcheries that lose their accreditation, or have had accreditation suspended, should not be permitted to move saucer scallop spat within the State in which they operate.

4. Sampling of spat for health certification

a) Samples from each batch of saucer scallop spat must be submitted for examination for a health certificate once the majority of spat are >2 mm dorso-ventral height (using a 2 mm x 2 mm grid to separate spat of appropriate size) or 14 days prior to the removal from the hatchery. The pathologist will issue a health certificate within 14 days unless further testing is required or the sample submitted is unsuitable. Spat may be moved from the hatchery once the health certificate has been endorsed.

b) A total sample of at least 300 spat of appropriate size, with a sub-sample to be taken from each of the tanks containing spat, should be fixed in 10% formalin seawater as directed by persons competent and accredited as pathologists from relevant State authorities. This sample should be submitted to the Fish Health Section for health certification, or to another laboratory as approved by the relevant State fisheries authority.

c) Details of the origin of the broodstock and the current health status of the hatchery are to accompany the sample.

d) The pathologist may also request an audit of the logbook relating to the batch to be tested and the hatchery operations logbook over the period of rearing.

5. Disease testing protocol

a) Each batch of spat will be subjected to the following tests and examinations by the persons competent and accredited as pathologists from relevant State authorities:

- Histological examination of at least 150 spat (10% formalin seawater fixed), using haematoxylin and eosin stained sections of paraffin embedded tissue;
- Further histochemical stains and electron microscopy at the certifying pathologist's discretion; and
- Any further tests or samples taken as deemed necessary by the certifying pathologist.

b) A health certificate for each batch of spat will be issued by the approved pathology laboratory subject to the batch not showing any signs of significant pathogens or lesions.

c) The presence of any of the following signs of disease or lesions may be reason enough for a health examination certificate not to be issued:

- Any virus associated with a lesion (e.g. inclusion bodies or focal necrosis) or a virus known or suspected to be pathogenic to saucer scallops.
- Any protozoan associated with an inflammatory or degenerative lesion or a protozoan known or suspected to be pathogenic to saucer scallops. (Note: The presence of symbiotic or opportunistic protozoa will not be regarded as a sign of disease).
- Metazoan parasites that cause a lesion in saucer scallops or which are suspected to be pathogenic for the species in question.
- A fungal infection that causes lesions (e.g. Necrosis/inflammation) in saucer scallops.
- Bacteria associated with lesions or inflammation.
- *Rickettsia* associated with lesions or inflammation.
- Unexplained lesions.
- Unexplained mortalities in the batch at a level that the certifying pathologist considers unacceptable.

6. Reporting protocol for disease testing of hatchery spat

a) The certifying pathologist will advise the relevant office of the State fisheries authority Australia, and the client, of the results of the disease testing within one day of the test being completed. A copy of the results will be faxed to the relevant office and to the client.

b) The original Health Certificate will be forwarded on to the relevant office of the relevant State fisheries authority and a copy sent to the client.

c) A duplicate copy of the Health Certificate is to be retained by the hatchery/company and must accompany the batch of spat during any transportation.

7. Protocol for the sales of hatchery produced spat

a) Once the batch of larvae are grown to the size required for release and an approved Health Certificate has been issued, the spat can be removed to an approved release site.

b) As a precautionary measure, a sample of 150 spat shall be taken immediately before departure from the hatchery and preserved as a reference sample by the hatchery. The sample must be kept by the hatchery for a period of three months and, if requested, provided to the relevant State fisheries authorities or appropriately authorised pathologists during this period.

c) When selling any batch of spat with appropriate Health Certification, the owner should be required to complete a consignment note in triplicate. One copy is to accompany the consignment of spat, one is to be retained for a period of seven years in the hatchery facility and one to be forwarded to the relevant State within 24 hours of the date of consigning.

8. Destruction of spat

a) In order to ensure the adequate control of significant diseases within the aquaculture industry, the relevant State Fisheries and Primary Industry authorities have legislated power to order the quarantine or destruction of saucer scallop spat if there is sufficient suspicion or evidence of significant disease.

b) The relevant authority for the State fisheries agency should receive notification from the certifying pathologist that a batch of spat has failed the disease testing. This notification shall be given within one day of the finalisation of the results of the tests. The notification should be the Health Certificate faxed to the relevant State fisheries office and the client. The original Health Certificate should be forwarded to the relevant office of the State fisheries agency and the client within three days of finalisation of the results of the tests.

c) Within 24 hours of receipt of the faxed advice that a particular batch of spat had failed testing, the hatchery/company may be required by the delegated State authority to destroy the entire batch or part thereof located in the hatchery by incineration or any other method specified by the delegated officer.

9. Cleaning and disinfection schedule

a) Cleaning

All tanks, containers, external pipe surfaces, buckets, nets and boots should undergo a thorough mechanical cleaning using a 1% solution of sodium hydroxide (10g/Litre) at 60°C by means of a brush or high pressure spray, or an alternative schedule as approved in writing by authorised officers and/or persons competent and accredited as pathologists from relevant State authorities.

Each tank containing stock should have allocated to it a designated set of equipment (i.e. buckets, nets, brushes).

b) Disinfection

All entrances and exits to the hatchery facility should have footbaths containing 100ppm chlorine or other disinfectant approved by persons competent and accredited as pathologists from relevant State authorities. The chlorine solution in the footbaths should be changed on a daily basis.

Following cleaning, all tanks and equipment are to be dried and then disinfected with a solution containing 60ppm free chlorine, with a contact time of no less than 60 minutes. All surfaces must be kept wet with the disinfecting solution during the 60 minutes.

Disinfection procedures in a hatchery where a batch has failed Health Certification should be carried out under the specific direction of a person competent and accredited as a senior pathologist from relevant State authorities.

c) Rinsing

All equipment shall be rinsed free of disinfectant using clean sea water or fresh water.

d) Drying

Rinse water should be drained from all surfaces and the equipment allowed to dry before introducing any new batches of broodstock or post larvae.

Identify hatchery-reared animals and assess stocking impacts

We have considered the issue of identifying hatchery-reared animals and differentiating them from wild stock in Section 5.2.2. On the basis of our experience, we believe that differentiating between hatchery reared and wild saucer scallops will not be a major challenge.

Use empirical processes to define optimum release strategies

We have referred to the need for further studies on transport procedures for saucer scallop spat. The same is true for release procedures. There is, understandably, no information available on optimum procedures for releasing hatchery-reared saucer scallops to minimise mortality. Alternatives that might be considered include surface release and a range of strategies for releasing juveniles on the seabed. Optimising size at release may be critical for the economic success of a marine ranching operation. There will be a balance between the costs of growing out very large numbers of spat to a given size in a controlled onshore environment and the benefits of reducing predation by releasing spat at a size large enough to minimise mortality. We have guessed at a size of release for the purpose of modelling economic viability of an enhancement or marine ranching operation. Hard data on these parameters should be sought as a priority issue in a research phase for a re-seeding project.

5.4 Preliminary feasibility study, benefit-cost analysis (Objective 3)

5.4.1 Introduction

The following benefit-cost analysis examines the economic feasibility of enhancing saucer scallop production in Australia through marine ranching. There is a unique opportunity to develop saucer scallop fisheries in Australia, based upon the re-seeding of hatchery-reared scallop onto managed areas of seabeds. The success of the New Zealand Challenger operations was a dramatic demonstration of the benefits of sustainability and economic gain that can be obtained from the seeding of scallops for commercial harvest.

The model is based upon the concept of a venturer (private company, cooperative or other arrangement) undertaking a research and development phase in conjunction with government research providers and research agencies. This R&D phase would be based upon developing techniques and obtaining relevant data to questions raised in Sections 5.1 and 5.2. The operation would then develop into a commercial entity by developing a (private) hatchery, obtaining an exclusive access area agreement with government and commencing a re-seeding and harvest operation in a discreet area.

5.4.2 Objectives

The objectives of the economic study and model were to assess:

- the cost and output of a research and development program;
- the likely success of a pilot re-seeding operation utilising an existing research facility as a source of spat for pilot operations;

- the likely profitability of a commercial scallop hatchery and integrated re-seeding and harvest operation;
- the economic consequences of both high and low risk options in relation to saucer scallop enhancement;
- the size of hatchery required for commercial viability;
- the sensitivity of profitability to changes in yield and price.

5.4.3 Methods

The economic feasibility of scallop enhancement was evaluated using a bio-economic modelling process, based upon the scenario of using scallop spat supplied from a hatchery, an open water seeding process, and a recapture process using existing fishing technology and existing vessels. Costs from this exercise were largely based upon assumption and experience rather than empirical observation. However, the data were based upon the experience of project team members (Mercer, Heasman, Duncan, Whittingham, Joll, Dredge, Johnston) who collectively have as much experience in the cost structure of shellfish hatcheries, scallop capture and aquaculture economics as any equivalent group in Australia.

The economic analysis and modelling of a saucer scallop enhancement program is broken up into alternative procedural options—high and low risk ventures. The risk differential is based on the existence of a pilot re-seeding venture to be undertaken by a government run research facility, such as the Bribie Island Aquaculture Research Centre (BIARC). This would entail developing hatchery capabilities and procedures at a pilot scale leading to a small scale re-seeding of a controlled seabed to test the success of the enhancement program, prior to a commercial hatchery and harvesting venture being established. This provides lower risk (on the basis of improved information and decision-making capacity) but longer time leads for the commercial venturer. The higher risk alternative would be to establish a commercial hatchery based solely on existing research and development into scallop hatchery techniques without a pilot scale seabed trial.

A number of stages exist within the high and low-risk ventures. These stages are illustrated in the following diagram (Figure 5.1).

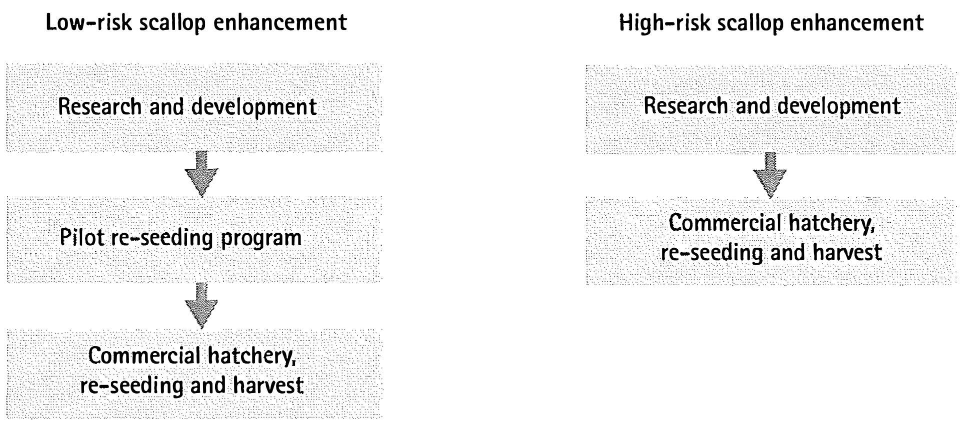


Figure 5.1 Project stages

We have modelled costs and benefits of a (theoretical) marine ranching project using these four basic scenarios. The detailed (Excel®-based) models are given in Appendix 2, on the accompanying CD-ROM. For the purpose of evaluating the various approaches to a scallop enhancement project, a period of 20 years has been chosen. The time frame for the low-risk scallop enhancement program is three years for research and development, four years for the pilot re-seeding and harvest, and the remaining 13 years for the commercial development. The high-risk program involves three years of research and development followed directly by the establishment of the commercial hatchery and re-seeding operation (17 years).

Data collection and modelling process

Scale of operation

Data collection and the modelling process were initiated using a given output of scallop meat. We used a production level of 100 tonnes of scallop meat as the (arbitrary) basis for costs and benefits. The level of production was chosen on a pragmatic basis, as this amount of scallop meat would generate sufficient revenue to be worth the commitment of investment funding but not to have an appreciable impact upon existing supply and market prices. As it eventually turned out, the hypothetical production level required hatchery facilities and re-seeding areas that were within the bounds of practicality and scale of existing hatchery operations.

Biological parameters

To generate 100 tonnes of scallop meat (ca. 500 tonnes total weight) requires the capture of 10 million scallops, each of which gives 10g of meat. Assuming 50% capture efficiency for repeat trawls over an area (Joll and Penn 1990) and a total 80% of available scallop being captured, a total of 12.5 million commercial scallops need to be alive at the time of harvest.

We assumed that harvest would occur at a size of 90 mm, when re-seeded scallops would be ca. 32 weeks of age post-settlement. We also assumed a summer – autumn harvest, when meat condition of saucer scallops is optimal. The estimates of age, growth and condition are based upon tagging and serial size frequency data sets (Williams and Dredge 1981, Dredge 1985a, Dredge *et al.* m/s). We assumed that seeding would occur at a size of 10 mm.

Survivorship data are based upon an estimate of natural mortality of 0.02 week^{-1} for 60–100 mm scallops (Dredge 1985b). We assumed that instantaneous natural mortality rates (M) of the younger scallops would be considerably higher than that of the older animals. We therefore varied the estimated value for M with size and age, loosely basing the ratios of M against age upon data given by Wang and Heywood (1999) for banana prawns, given the absence of equivalent age-specific natural mortality rates for saucer scallops. Details are given in Table 5.1. All parameters can be (and have been) varied interactively for determining model sensitivities to these parameters.

Table 5.1 Morality rates and coefficients for scallops used in the bio-economical model

Scallop size (mm)	Natural mortality Coefficient (M, week^{-1})	Duration of size phase (weeks)	Survival rate (%) over time
10 to 30 mm	0.09	5	63.8
30 to 50 mm	0.06	5	74.1
50 to 90 mm	0.02	15	74.1

By back-calculating from the required number of harvest-size scallops and given the size-specific natural mortality rates given in Table 5.1, an estimated number of 35 million 10 mm saucer scallops were required for re-seeding. We went through a similar exercise to estimate that 178 million settled spat would be required to supply 35 million 10 mm juveniles for re-seeding. Natural mortality rates of scallops in the hatchery and nursery phases were based upon conservative interpretation of survival rates observed by Wang and Duncan (pers. com.) in ongoing pilot studies.

The highest known catch rates of saucer scallops we have observed in the wild in Queensland waters equates to a density of approximately one animal per square metre. This is considerably less than peak densities of *Placopecten magellanicus* described by Caddy (1968) and is probably a conservative maximum density figure in the light of catch rates and implied densities observed in Shark Bay during a peak in settlement observed by Joll in 1993–4. On this basis, we suggest that an exclusive access area of 12.5 km^2 (12.5 $*10^6$ scallops*1 (harvestable) scallop m^2) would be required as an exclusive access area for scallop enhancement in order to generate a 100 tonne enhancement operation. Alternatively, an area of 0.625 km^2 would be needed for a pilot operation generating 5 tonnes of scallop meat, using the same mortality estimates and logic given above.

Cash inflows and outflows

The cash inflows of the two projects (low and high risk) are assumed to come from two sources. The first is research funding provided by agencies such as State fisheries research agencies and state development agencies, research funding agencies such as the Fisheries Research and Development Corporation (FRDC) and potential investors, perhaps including elements of the scallop trawl industry. The second is derived from the sale of the harvested product (yield * price).

In assessing the likely profitability of the scallop enhancement projects, no consideration was given to catastrophic losses that might occur. Loss of production through disease, water quality problems, unforseen environmental conditions and lack of experience could potentially reduce output and severely reduce the profitability of the enterprise, but cannot be effectively modelled without any information on, or insight into, frequency or severity of catastrophe.

The cash outflows of the projects include the capital and operating costs of the projects. A summary of the cost structures for each of the projects are shown below. For a more detailed breakdown of costs refer to the CD-ROM that accompanies this report (Appendix 2). A comprehensive bio-economic model has been developed for each project, and each stage of the project. It has been developed using Microsoft Excel®. Detailed model structure can be examined using the 'Format/Sheet/Hide-Unhide' feature in Excel, and parameters can be varied using the 'Tools/Protection/Protect Workbook' feature.

Details of the cost and revenue structure are given in each of the four models in Appendix 2. Briefly, we have costed the hatchery operations using the following inputs:

- Land costs are based on current coastal land values in southern-central Queensland and a 100% salvage value is applied at the termination of the (20 year) project lifespan;
- Capital equipment estimates are based upon recent equivalent costing for barramundi, oyster, and prawn hatcheries (Johnston 2000). This includes buildings, vehicles, machinery, water recirculation system, tanks, pipelines and pumps, algal food production and miscellaneous equipment;
- Labour costs are based upon current Queensland aquaculture industry standards;
- Hatchery-operating costs are based upon current Queensland aquaculture industry standards, and from information supplied by project team members. They include fuel, oil, repairs and equipment maintenance, electricity, vehicle costs, insurance and administrative costs. These costs are categorised as operating, given their annual recurrence;

- Packaging and freight of juvenile scallops for re-seeding was based upon current best practice in the aquaculture industry, but accepting a high degree of uncertainty about the cost for oceanic transport of young scallops from the hatchery;
- Harvest and processing costs were based upon the requirement of 150 boat days for harvesting the 100 tonnes of scallop meat generated in our full-production scenario. The expected cost of harvest per vessel day is $1500 based upon existing fuel prices, operating costs, and industry processing costs of $2.00 per kilogram of scallop meat. These costs have been scaled accordingly to assess the cost of the pilot operation.
- Social and opportunity costs associated with the loss of 12.5 km^2 of fishing ground exist to the industry (See Section 4.4.3.). Given, however, this represents about 0.05% of the total scallop fishing ground in Queensland, we believe the cost will be trivial to the remainder of the industry excluded from the re-seeding area, but has been accounted for in the bio-economic model. The West Australian marine ranching operational permit has been issued in an area currently closed to trawling. There is no loss to the fishery in that case.
- In each enhancement scenario we have allowed $50 000 annually for the cost of monitoring the exclusion zone, and a further $40 000 annually for the scientific monitoring of the seabed.
- We have used a fixed price of $25.00 per kilogram for scallop meat, based upon current beach prices for premium grade scallop meat exported to Hong Kong as of May – August 2001 (Whittingham pers. com.). Again, model structures allowed for sensitivity analysis to be undertaken to determine break even prices.

Computer modelling process

Four models have been used to describe economic performance of a saucer scallop enhancement project. These cover research and development for the operational phases of the low-risk enhancement project (i.e. using a pilot operation) and the high-risk (no pilot phase) scenarios in addition to the operational phases for both scenarios.

Throughout the modelling process interactive and sensitivity-driven processes have been used. These enable input parameters to be varied, and for critical values of input parameters to be assessed by driving them to a model state of zero economic return.

Data analysis

Discounted cash flow analysis was used to determine the annual cost structure and the likely loss/profitability of each stage of the high and low-risk projects. Discounting reduces a time stream of costs or benefits to an equivalent amount in today's dollars. People generally prefer to receive a given amount of money now rather than to receive the same amount in the future, because money has an 'opportunity cost'. For example, if asked an amount of money they would just prefer to receive in 12 months time in preference to $100 now, most people would nominate a figure around the $110 mark. In other words, to them money has an opportunity cost of around 10 per cent. A dollar tomorrow is not worth the same as a dollar today, both through inflation and uncertainty. Therefore, the timing of these projects has an influence on the annualised costs and revenues of the project. The single amount calculated using the compound interest method is known as the present value (PV) of the future stream of costs and benefits. The rate used to calculate present value is known as the discount rate (opportunity cost of funds).

Analysis of the two scallop enhancement programs assumed a project life of 20 years and used a real discount rate of 8 per cent to calculate the net present value (NPV). The budgets also incorporate the initial capital and establishment costs.

Four profitability measures, and a measure of financial risk, were used to evaluate the model farm:

Net Present Value (NPV)

The NPV is the difference between the present value of cash inflows and the present value of cash outflows over the life of the project. A positive NPV is indicative of a profitable project.

Equivalent Annual Return

When the NPV is converted to a yearly figure it becomes annualised. In this report the annualised return is called the Equivalent Annual Return. It is a measure of annual profit after deducting capital, operating and labour costs generated over the life of the project expressed in today's dollars.

Internal Rate of Return (IRR)

The discount rate at which the project has an NPV of zero is called the internal rate of return. The IRR represents the maximum rate of interest that could be paid on all capital invested in the project. If all funds were borrowed, and interest charged at the IRR, the borrower would break even, i.e. recover the capital invested in the project. The IRR may not be used in cases where there are negative values in the cashflow.

Benefit Cost Ratio

The ratio of the expected present value of project benefits to the expected present value of project costs. For example, a ratio of 1 to 1.5 indicates that every dollar invested in the project will return $1.50.

Payback period

Payback period is a measure of the attractiveness of a project from the viewpoint of financial risk. Other things being equal, the project with the shortest payback period would be preferred. It is the period required for the cumulative NPV to become greater than zero and remain greater than zero over the life of the project.

Scope of the study

The calculations were based on the following assumptions:

- Land is salvaged at 100 per cent of the original price, paid at the termination of the project. The real value of land was maintained over the life of the project;
- Taxation was excluded from the calculations;
- The total area of the model hatchery and nursery ponds was one hectare, of which 0.28 hectares were used for juvenile nursery ponds;
- Equivalent annual returns were calculated net of owner/operator labour, capital and operating costs;
- Prices and costs used in the analysis were based on information supplied by the project team;
- The analysis assumed there was no major unforseen losses of stock (such as disease outbreaks) over the production period;

- The opportunity cost of time spent establishing the enterprise was not included as an economic cost.

The models were structured on the commercial phase of the operation producing an arbitrary 100 tonnes of scallop meat (worth $2.5 million at prices as of May–August 2001). The production figure was chosen on the basis of being significant in the context of existing fisheries for saucer scallops, without being at such levels that could impact on markets. If target production levels fell below 100 tonnes, we felt that revenue of less than $2.5 million would be trivial in terms of the costs and organisation required in instigating an enhancement operation. Many of the major input parameters, such as seabed area required, have been back-calculated on the basis of this figure of 100 tonnes and the known densities at which saucer scallops have been previously recorded. The commercial operations, (high and low risk) are effectively identical except for time of establishment.

Table 5.2 Operational parameters

Parameters	Pilot	Commercial
Production target (meat)	5 tonnes	100 tonnes
Harvest target (scallops)	25 tonnes	500 tonnes
Scallop size at harvest	90 mm	90 mm
Scallop weight at harvest (Meat weight)	10 grams	10 grams
Output of 10 mm spat	1 7800 000	38 000 000
Re-seeding area (square km)	0.625	12.5
Spawning per year (winter-spring)	4	4

5.4.4 Scallop enhancement (Low risk)

Revenues

The low-risk scallop enhancement project is broken up into the following three stages as mentioned previously:

1. Research and Development (3 years)
2. Pilot re-seeding and harvest (4 years)
3. Commercial hatchery, re-seeding and harvest (13 years)

Cash inflows for stage one (the R&D phase) are derived from a 50:50 split in support from a research support agency and private enterprise. The funding support totals $100 000 per annum for three years from each, a total of $600 000 for the completion of the research and development phase.

The pilot program has two sources of cash inflows. The first is further support from a research support agency and the venturer. External funding support is estimated at a reduced $50 000 per annum over the four years of the pilot project, while the industry will maintain its annual support of $100 000 per annum. Over four years, total cash inflows for the pilot stage will total $600 000. This funding breakdown is not critical, as the total funding availability, rather than its source, will drive the project.

The second source of income for the pilot program will be derived from the harvest of scallops from the pilot seabed site. It is estimated that five tonnes of scallop meat will be harvested from the pilot site and will receive a market value of $25.00 per kilogram. Annual income derived from the pilot harvest is therefore estimated at $125 000 per annum. Income from the harvest will only occur in the last three years of the pilot stage because of the lag time between the first re-seeding and the first harvest.

The commercial phase of the project will rely solely on private enterprise funding and will, therefore, retain all income from the harvest of the seabed site. The size of the commercial harvest is estimated at 100 tonnes of scallop meat at the expected market price of $25.00 per kilogram, giving an annual gross income of $2 500 000. Cost recovery for the R&D phase may require consideration, but will depend on cost recovery policies of potential research suppliers.

Costs

Low-risk scallop enhancement project – R&D and pilot phase

For the purpose of this study it is assumed that during the three years of research and development, hatchery techniques and processes will develop to the point at which adequate numbers of spat can be supplied for re-seeding of the pilot seabed site. As the research facility hatchery will be scaled up over the three years, costs will also be scaled up at the same rate. For the pilot phase, a target hatchery output of 1 800 000 spat is assumed to be the maximum level of output needed, and that level will be maintained throughout the pilot phase (refer to computer models in Appendix 2 for further explanations).

Table 5.3 Cost multipliers for the low-risk scallop enhancement project.

Year and phase	Cost multiplier
1 (R&D)	10 %
2 (R&D)	40 %
3 (R&D)	80 %
4 (Pilot)	100 %
5 (Pilot)	100 %
6 (Pilot)	100 %
7 (Pilot)	Pilot hatchery operation finished

Annualised costs incurred over the seven years of the research and development and pilot phases are given in Table 5.4.

Low-risk scallop enhancement project – commercial phase

The commercial phase of the low-risk project begins towards the end of year 7 of the 20-year project and is evaluated accordingly (Table 5.3, Fig. 5.2).

Table 5.4 Annualised cost structure for the low-risk scallop enhancement project – R&D and pilot phases.

Cost description	
Feeding – algae and fertiliser	$1 341
Labour	$106 598
Water	$367
Repairs and maintenance	$2 993
Electricity	$5 986
Other operating (phone, insurance, lease etc.)	$17 957
Packaging and transport of spat	$451
Harvesting	$3 820
Capital purchase and replacement	$21 166

Table 5.5 Annualised cost structure for the low-risk scallop enhancement project – commercial phase

Cost description	
Feeding – algae and fertiliser	$13 284
Labour	$96 057
Water	$4 003
Fuel, oil, repairs and maintenance	$21 137
Electricity	$11 743
Other operating (phone, insurance, lease etc.)	$6 365
Packaging and transport of spat	$10 791
Harvesting and monitoring	$147 962
Fleet cost (cost to excluded boats)	$20 387
Capital purchase and replacement	$67 663

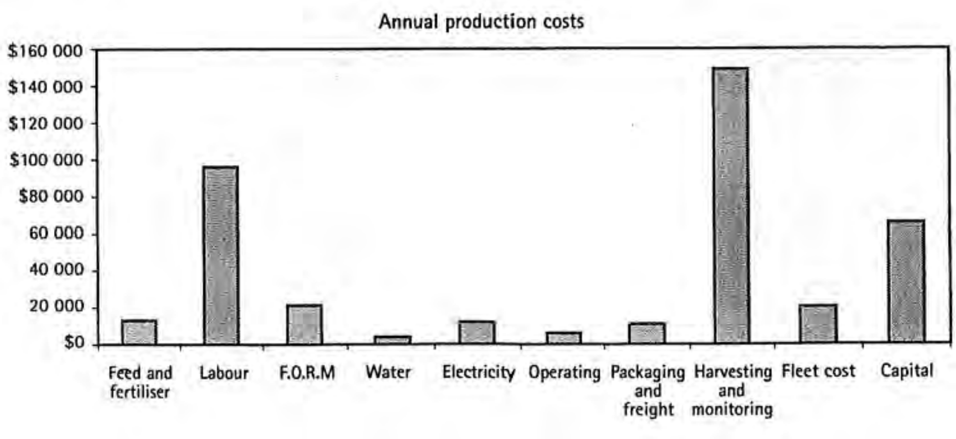


Figure 5.2 Annual production costs for the commercial phase of the low-risk enhancement operation

5.4.5 High-risk scallop enhancement program

The high-risk scallop enhancement project is broken up into the following two stages as mentioned previously:

1. Research and Development (3 years)
2. Commercial hatchery, re-seeding and harvest (17 years)

The cash inflow for the high-risk project mirrors that of the low-risk project detailed above, except for the exclusion of the pilot phase. A total of $600 000 will be supplied over the three years of the research and development phase, with a component coming from an R&D support agency and the remainder from the private venturers. There is no pilot phase, but a transition directly into commercial production. The size of the commercial annual harvest is estimated at 100 tonnes of scallop meat at the expected market price of $25.00 per kilogram giving an annual gross income of $2 500 000.

Revenues

The high-risk project has a research and development phase similar to that of the low-risk project. However, the cost multipliers are different because the project enters the commercial phase directly following the R&D phase (Tables 5.6, 5.7). As there is no pilot study in this instance the R&D phase must be scaled up. Opportunity for further monitoring and development is lost due to the absence of the pilot re-seeding and harvest. The risks associated with this option are greater than for a project with a pilot phase. Operational failures will occur at commercial scale costs.

Table 5.6 Cost multipliers for the high-risk scallop enhancement project

Year and phase	Cost multiplier
1 (R&D)	10 %
2 (R&D)	50 %
3 (R&D)	100 %

Table 5.7 Cost structure for the high-risk scallop enhancement project – R&D phase

Cost description	
Feeding – algae and fertiliser	$1 143
Labour	$120 052
Water	$313
Repairs and maintenance	$2 552
Electricity	$5 103
Other operating (phone, insurance, lease etc.)	$15 309
Capital purchase and replacement	$14 910

Costs

The commercial phase of the high-risk project begins in year four of the 20-year project and has been evaluated accordingly (Table 5.8, Fig. 5.3).

Table 5.8 Annualised cost structure for the high-risk scallop enhancement project – commercial phase

Cost description	
Feeding – algae and fertiliser	$20 857
Labour	$150 821
Water	$6 284
Fuel, oil, repairs and maintenance	$33 188
Electricity	$18 438
Other operating (phone, insurance, lease etc.)	$9 993
Packaging and transport of spat	$16 944
Harvesting and monitoring	$232 318
Fleet cost (cost to excluded boats)	$32 010
Capital purchase and replacement	$103 625

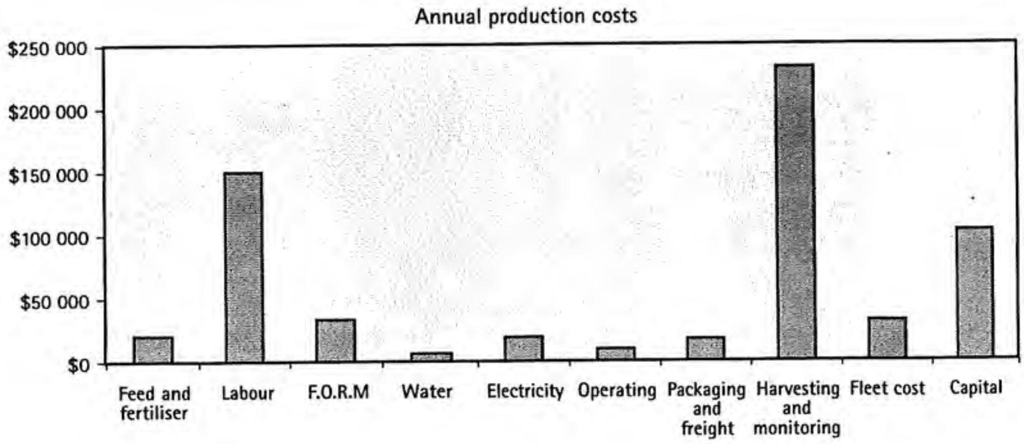


Figure 5.3 Annual production costs for the commercial phase of the high-risk enhancement operation

5.4.6 Results

Profitability and sensitivity

Measurement of the likely profitability of the two scallop enhancement scenarios was based on two profitability measures (see Section 5.4.3.). They were equivalent annual return and internal rate of return (IRR). The analysis was carried out over a project life of 20 years using a discount rate of 8 per cent.

Low-risk scallop enhancement project

As mentioned above, the low-risk scallop enhancement project consists of three phases: research and development, pilot hatchery and re-seeding, and the commercial phase. The project was evaluated as a whole in the initial analysis.

The net present value of the 20-year low-risk project was $6.7 million. The benefit cost ratio for the project is 2.3, which indicates a $2.30 return for every dollar invested in the project.

The research and development/pilot phases have been evaluated separately to the commercial operation in addition to taking a holistic approach to the 20-year project. This allows an assessment of each component and a review of their ability to provide successful outcomes. The research and development phase runs for three years and leads into a pilot hatchery and re-seeding phase that extends for a further four years. These two have been evaluated as one project as we envisage the majority of work and assessment will be carried out in a single site. Data in Table 5.9 summarises the results of the research and development/pilot phase.

Part of the revenue received is derived from funding inputs, in addition to revenues from the pilot harvest. The pilot harvest generates revenues in the last three years of this component. Given a price of $25.00 per kilogram for scallop meat and the estimated production of 5 tonnes from the pilot harvest the equivalent annual return over the period of research and development and the pilot was approximately $60 000 (Refer to Appendix 2 for details). Formal economic analysis shows that the research and development/pilot is, hypothetically, profitable. A benefit cost ratio of 1.4 indicates a $1.40 return for every dollar invested in this phase of the project. The discounted cumulative cash flow for this component is illustrated below. We have some reservations about the significance of this analysis and advise that its results should only be treated as indicative. Revenue is partly obtained from research funding providers, which generally supply funding for the public good, and for which meaningful economic returns are difficult or impossible to estimate. Building such funding into an economic model has complex implications for returns on investment that are beyond the scope of this project. At the same time, the research and development/pilot phase was designed to supply data that could be used to evaluate the reality of many assumptions we have made in our models. Costing and evaluating the economic returns for such a data gathering exercise again goes beyond the scope of the straightforward and simple economic models we have used.

Table 5.9 Economic indicators for the low-risk research and development/pilot phase

Indicators	Results
Net Present Value	$349 378
Equivalent Annual Return	$67 106
Benefit Cost Ratio	1.44
Payback period	Year 2 of operation
Average annual gross revenue	$220 228
Average annual production cost	$160 679

The commercial operation is assumed to commence in year 8 of the 20-year project. Table 5.10 shows the economic indicators for the commercial operation. Capital investment in the commercial operation occurs in year 7 and no revenue accrues to the commercial venture until year 9 due to establishment lags (Figure 5.4).

Table 5.10 Economic indicators for the low-risk commercial phase

Indicators	Results
Net Present Value	$6 57 487
Equivalent Annual Return	$651 186
Benefit Cost Ratio	2.60
Internal Rate of Return	59 %
Payback period	Year 2 of operation
Average annual gross revenue	$1 036 730
Average annual production cost	$399 391

Based on the selected price of $25.00 per kilogram for scallop meat and the estimated production of 100 tonnes of scallop meat, the expected equivalent annual return over the life of the project was approximately $637 339. The internal rate of return was 59 per cent. This is equivalent to a maximum real rate of interest an investor could pay if all the funds invested in the venture were borrowed. It was estimated that it would take two years to recoup the original investment in the project.

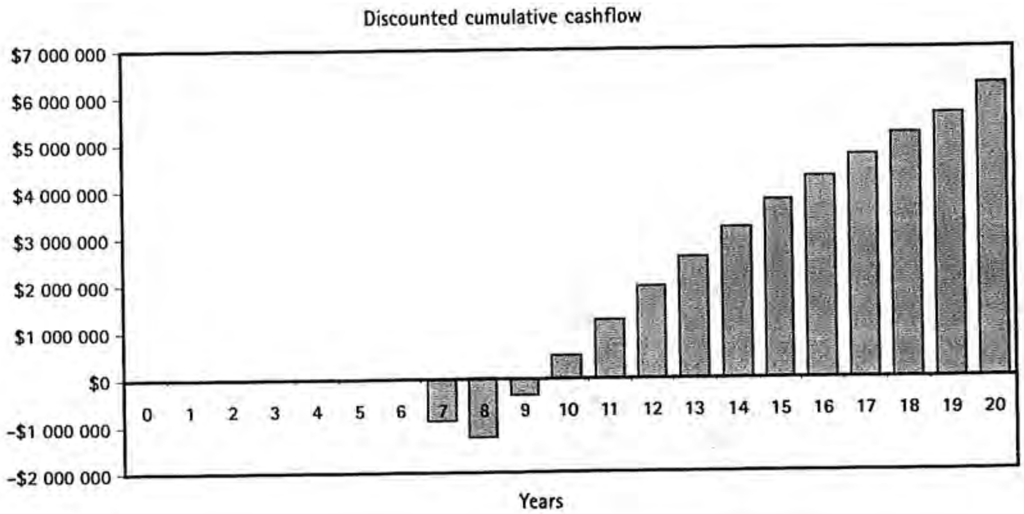


Figure 5.4 Discounted cumulative cash flow for the commercial phase of the low-risk enhancement operation (initiated in year 7 of the 20-year project)

The largest cumulative deficit (peak debt) was incurred in year 8 of the project. The deficit was modelled to be $1 237 430. This deficit reflects the capital required to establish the enterprise and the operating costs of the establishment year. The cash flow position improved over the life of the project and became positive in year 9 of the project, equivalent to the end of year 2 in the commercial operation.

The profitability of the commercial enterprise in regard to sensitivity can be illustrated by the production cost per kilogram of scallop meat in relation to the market price received. The production cost per kilogram of scallop meat was calculated at $9.63. Therefore, a price fall of greater than $15.70 per kilogram (>60%) would be required to create a loss (an equivalent annual return of less than zero). It is estimated that the project will harvest 100 tonnes of scallop meat annually when fully operational. For profits to reach zero the quantity of scallop meat harvested would have to fall below 33 tonnes (out of a possible 100 tonne harvest).

High-risk scallop enhancement project

The high-risk scallop enhancement project consists of two phases: research and development and the commercial phase. In the first set of results the project is evaluated as a whole.

The Net Present Value of the 20-year high-risk project was close to $10.2 million. The Benefit Cost Ratio for the project is 2.65 which indicates a $2.65 return for every dollar invested in the project.

The research and development phase runs for three years and leads directly into the establishment of the commercial operation. The research and development phase of the project only receives revenues from funding sources. It is possible to calculate the minimum level of funding to support research and development at an existing research facility. The minimum level of funding required was calculated at approximately $165 000 per annum. No values have been included regarding the profitability of the research and development phase as they are solely dependent on the level of funding provided by research funding providers and the commercial venturers.

The commercial operation is assumed to commence in year 4 of the 20-year project. Table 5.11 and Figure 5.5 show the economic indicators for the commercial operation. Capital investment in the commercial operation occurs in year 3 and no revenue accrues to the commercial venture until year 5 due to establishment.

Table 5.11 Economic indicators for the high-risk commercial phase

Indicators	Results
Net Present Value	$10 133 826
Equivalent Annual Return	$1 032 153
Benefit Cost Ratio	2.65
Internal Rate of Return	59 %
Payback period	Year 3 of operation
Average annual gross revenue	$1 656 631
Average annual production cost	$624 479

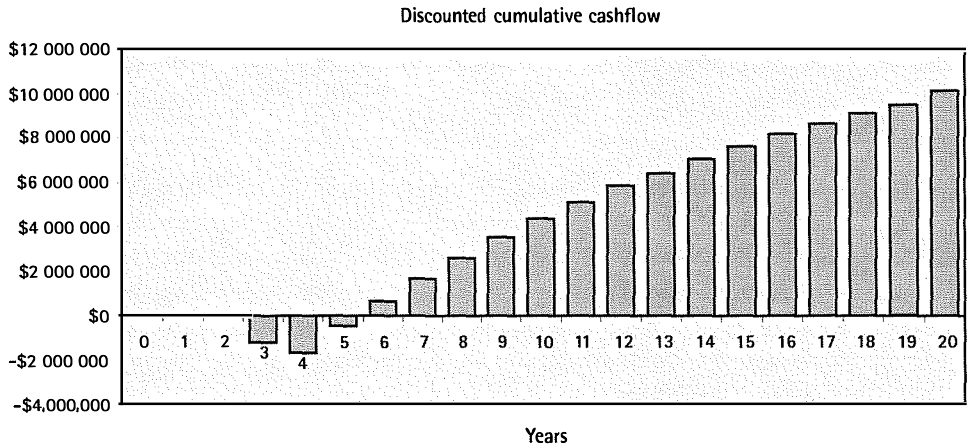


Figure 5.5 Discounted cumulative cash flow for the commercial phase of the high-risk enhancement operation (initiated in year 3 of the 20-year project)

Considering the selected price of $25.00 per kilogram for scallop meat and the estimated production of 100 tonnes of scallop meat, the expected equivalent annual return over the life of the project was approximately $1 032 153. The internal rate of return was 59 per cent. This represented the maximum real rate of interest an investor could pay if all the funds invested in the venture were borrowed. It was estimated that it would take two years to recoup the original investment in the project.

The largest cumulative deficit (peak debt) was incurred by the project in year 5. The deficit was modelled as $1 683 510. This deficit comprised the capital required to establish the enterprise and the operating costs of the establishment year. The cash position improved over the life of the project and became positive in year 7 (year 4 of the operation).

The profitability of the commercial enterprise in regard to sensitivity can be illustrated by the production cost per kilogram of scallop meat in relation to the market price received. The production cost per kilogram of scallop meat was calculated at $9.42.

Therefore, a price fall of greater than \$15.58 per kilogram (> 65%) would be required to create a loss (an equivalent annual return of less than zero). It is estimated that the project will harvest, on average, 100 tonnes of scallop meat annually. For profits to reach zero the quantity of scallop meat harvested would have to fall below 34 tonnes.

Biological sensitivity

Assessment of an enhancement project's potential viability and profitability will be as much dependent upon the accurate estimation of biological parameters as good estimates of economic costs. We have only one estimate for the instantaneous natural mortality rate (M) of saucer scallops, for the size range 60–100 mm and have used this rate for this size range when modelling survival and economics of an enhancement operation. We increased our estimates of M by a factor of 3 for saucer scallops in the size range 30–60 mm, and by 4.5 for scallop in the size range 10–30 mm (Table 5.1), based on premises given by Wang and Haywood (1999). We recognise, however, that there is considerable scope for error in these estimates.

While we have reliable estimates for growth rates of saucer scallops in the size range 60–100 mm (SH) (Williams and Dredge 1981, Dredge 1985, Dredge *et al.* m/s), our estimates for the early phase of growth are based upon extrapolation, using conventional von Bertalanffy curve modelling. An imprecise estimate of growth will impact upon the duration of the growout phase and consequent survival of re-seeded scallops.

We intuitively suspected that model outcomes would be highly sensitive to variation in natural mortality rates and less sensitive to variation of growth rates of hatchery-reared and released spat. We therefore examined the potential profitability of the low and high-risk commercial operations using a range of estimated natural mortality parameters and growth rate parameters that are within the known range of growth rates described for *A. balloti*.

We had two potential procedures for estimating the sensitivity of the models' outputs to variation in M. One involved maintaining the proposed output of 100 tonnes of scallop meat, but varying the input process to allow for changing numbers of scallops to support this output. The alternative procedure was to simply vary the output of scallops with varying levels of M, while maintaining input parameters and costs at fixed levels. We chose the second procedure. This was, in part, due to the increased level of uncertainty the first procedure would entail. Operating a hatchery to produce a given number of spat entails considerable economies of scale as the project gets bigger, but there are also a series of step-wise functions associated with costs. These revolve around indivisible procedures, such as the number of labour units needed to produce given numbers of spat, the size of hatchery and land, and the size, number and complexity of infrastructure items. We had already made a number of assumptions about the input requirements for models, and felt that varying the model's internal structure to allow for increased costs in an uncertain but stepwise fashion would increase uncertainty and error to an unacceptable level. Further, the models' structures were not amenable to this type of change. The models have effectively been built in a top-down fashion from a given output of scallop, and input parameters such as labour and certain other costs were not designed for variation.

Two scenarios were used to vary M. One involved a direct, stepwise approach to increment values of M (0.005 week^{-1}) for all phases of growth/age. The second one involved the use of a fixed value for M in the size range 60–90 mm (for which we have hard data), and a more rapidly increasing (but still linear) function of instantaneous natural mortality for scallops in the size range 10–60 mm. Details are given in Tables 5.12 and 5.13, along with estimated values for average harvest, I.R.R. and Benefit Cost Ratios for each set of natural mortality values. Preliminary analysis showed some differences between NPVs and ARs between the low and high-risk scenarios, but virtually no differences between I.R.R. and

Benefit Cost Ratio estimators, so all modelling was based on the high-risk project and model. A single summary table for each set of values for M is given below.

Table 5.12 Estimated Internal Rates of Return (I.R.R.) and Benefit Cost Ratios (B:C) with varying estimates of M

Size range (shell height, mm)	10–30	30–60	60–90	Number of 90 mm shell (*10^6)	Estimated annual catch (tonnes)	IRR(%)	B:C
Estimated M (week^{-1})	.090	.060	.020	12.2	74.6	58	2.6
	.095	.065	.025	10.8	65.9	50	2.3
	.100	.075	.030	9.5	58.1	43	2.1
	.105	.075	.035	8.4	51.3	36	1.8
	.110	.080	.040	7.4	45.3	30	1.6
	.115	.085	.045	6.6	40.0	24	1.4
	.120	.090	.050	5.8	35.3	18	1.3
	.125	.095	.055	5.1	31.1	13	1.1
	.130	.100	.060	4.5	27.4	8	1.0

Table 5.13 Estimated Internal Rates of Return (I.R.R.) and Benefit Cost Ratios (B:C) with M fixed in the size range 60–90 mm, but varying in smaller scallops

Size range (shell height, mm)	10–30	30–60	60–90	Number of 90 mm shell (*10^6)	Estimated annual catch (tonnes)	IRR(%)	B:C
Estimated M (week^{-1})	.090	.060	.020	12.2	74.6	58	2.6
	.105	.070	.020	10.8	65.9	50	2.3
	.120	.080	.020	9.3	56.7	42	2.0
	.135	.090	.020	8.4	51.3	36	1.8
	.150	.100	.020	7.4	45.3	30	1.6
	.165	.110	.020	6.6	40.0	24	1.4
	.180	.120	.020	5.6	34.9	17	1.2
	.195	.130	.020	5.1	31.1	13	1.1
	.210	.140	.020	4.5	27.4	8	1.0

The analysis is basic, in that we have used determistic growth and mortality estimates and relied upon fixed input costs for all model scenarios. The overall impression, however, is that the profitability of an enhancement operation is surprisingly robust in the face of increasing natural mortality rates. We had to force M to levels of 0.21 week^{-1} for 10–30 mm saucer scallops (i.e. a weekly mortality rate of 20%) when maintaining M for larger scallops at best estimate before seeing IRRs and B:C Ratios approach to a zero profit situation. Such rates seem to be biologically extreme, but should be tested.

We also examined the consequences of variation in growth rate (von Bertalanffy's parameter k). The effect of reducing 'k' is to increase the time taken for scallops to reach a size of 90 mm, at which they should be harvested, and consequently, the time they are subject to natural mortality. We have varied 'k' between 0.046 and 0.061 in steps of 0.03, using a fixed value for $L_\infty$of 110mm, and estimated size at age for each 'k' value. The range of 'k' values lies outside the known range of estimates for this parameter. Age at size for each value of 'k' was then estimated, and the resultant variation in time taken for scallops to grow, and be subject to natural mortality, was then incorporated into the low risk scenario model to examine the impact of varying growth rates upon potential profitability. A summary of procedures and outcomes is given in Table 5.14.

Table 5.14 Effect of varying growth rate (and time between seeding and capture) upon economic performance of scallop enhancement operation

'k'	.046	.049	.052	.055	.058	.061
Size class	**Duration (weeks)**					
10–30 mm	6	6	6	5	5	4
30–60 mm	10	9	7	6	5	5
60–90 mm	18	18	17	17	15	14
Average annual harvest (tonnes)	47.6	50.5	58.1	67.6	74.6	83.3
I.R.R.	32%	36%	43%	51%	58%	65%
B:C ratio	1.7	1.8	2.1	2.4	2.6	2.9

Variation of the growth parameter 'k' around a reasonable range of known values, and consequent time between seeding and harvest, had some impact upon modelled project profitability and economic performance. The models, however, still indicate good profitability for a marine ranching project with saucer scallop growth rates being within the range tested. We are confident of the growth rates for scallops in the size range 60–90 mm, but suggest further work may be needed to verify growth rates of smaller scallops, particularly in the context of density dependent growth rate variation.

5.4.7 Conclusions

The economic analysis and bio-economic modelling of the low and high-risk saucer scallop enhancement projects, producing 100 tonnes of commercial output annually for an average price of $25.00 per kilogram, suggest that such projects should be highly profitable. Benefit Cost Ratios of between 1.3 and 2.65 are clear demonstration of abnormal profitability. Internal Rates of Return around 60% are exceptional in that they indicate a marine ranching project, if reliant on finance, would be able to commit funds at up to a 60% interest rate on capital and be able to maintain a breakeven position. In relation to other hatchery-based aquaculture, such as barramundi and prawns, the estimated rates of return for scallop re-seeding are far higher (Johnston 1999, 2000). On an international scale, a recent study by Penny and Mills (2000) suggests that the IRR for a venture based on sale of live 60 to 70 mm *Placopecten magellanicus* (Canadian scallop) to niche markets may be in the order of 30%. This venture was deemed economically viable if the IRR was greater than the current market interest rate on borrowed capital.

To put it in another perspective, the area of scallop ground in Queensland that can be trawled is approximately 24 000 square kilometres. This area produces around $25 million (wharfside landing value) for the State economy. The enhancement project requires 12.5 square kilometres, 0.052% of total trawl grounds, and is estimated to produce 10% of the total industry revenues. As mentioned before there is a cost to excluded vessels, which may be cause for concern, but given the small exclusion area the cost to each vessel is around $280 annually.

The potential profit projections are so high as to cause some concern or suspicion. Potential projects that predict benefits much above current interest and inflation rates have a consistent history of failing to meet predictions. The commercial phases for both the low and high-risk operations return annual profits of around $640 000 and $1 000 000 respectively, net of all expenses including capital replacement. Given the investment levels, these profits are substantial and indicate a sustainable and viable industry base from which further developments can arise. It would also be considered a major contributor to aquaculture production if it were to develop, particularly in Queensland. There would also be considerable flow-on social benefits, such as employment. We have spent some time examining why predicted profitability should be so high. The basic concepts of the operation are simple. An annual harvest value of $2.5 from 100 tonnes of scallop meat following a 3–7 year phase-in and pilot program seems to be achievable. Provided hatchery, monitoring and policing costs can be kept below $1.5–$2 m annually, the project should be profitable. The project team's experience on hatchery capitalisation and operating costs suggests these assumptions are reasonable. The basis for abnormally high profitability appears to be the very fast growth rate of ***Amusium balloti***, the relatively short time between seeding and harvest, and the high value of saucer scallop meat. The major areas of uncertainty are hatchery procedures and the time it will take them to be fully commercial, natural mortality rates and growth rates. We varied mortality and growth rate parameters in an exercise designed to show how much error our basic estimates for these parameters would lead to the project's economic failure. The models suggest that instantaneous mortality rates could be increased by as much as 2–3 times our original estimate while allowing (reduced) profitability. There is still, however, a strong case for undertaking field trials during a research and development phase, to examine natural mortality rates as functions of size, seeding location and seeding density.

Consideration should be given to the fact that the hatchery must be able to supply enough juvenile scallops to support the re-seeding, and that mortality on the seabed be kept to a minimum. The low-risk project, given a standard operational year and expected production, can withstand a 61% drop in market prices before carrying a loss. On the other hand, given steady market prices, the harvest of scallops would have to fall 65% (to ca. 35 tonnes) before a loss was recorded. The high-risk project would make a loss if prices dropped by 62% or production dropped 66% (to ca. 34 tonnes), given a standard year. Therefore, both the low and high-risk projects viability and profitability had a low sensitivity to price and yield fluctuations.

Given Benefit Cost Ratios of greater than one, IRR's of greater than the market interest rate, and a positive NPV/Equivalent Annual Return, both the low and high-risk enhancement options would be accepted on economic grounds. The high-risk option will lead into the commercial phase without a pilot phase and, therefore, has an increased chance of profit losses and failure. The low-risk enhancement option is open to the same risks when in the commercial phase, but decreases risk through the benefit of increased knowledge obtained in the pilot operation.

5.5 Developing an enhancement program for saucer scallops — business plan options (Objective 4)

The options under which an enhancement program for saucer scallops could be operated are almost limitless. On the basis of overseas experience and existing domestic organisational structures, there are, however, some basic premises and procedures that appear to be obligatory.

The first is that the enhancement operation needs be based upon hatchery-reared spat. This, in turn, calls for considerable knowledge, venture capital, infrastructure and expertise, and involves an appreciable delay between investment and return.

The second is an exclusive-use area of seabed in which enhancement can occur. The area would have to be gazetted and policed as an exclusion zone to trawlers other than those authorised to fish in the exclusive access area.

The third is the development of monitoring procedures and a harvest management plan and process.

Finally, the business plan must include a cost recovery process, to meet the needs and expenses of re-seeding, research and development, policing, monitoring and harvest.

We envisaged three general scenarios under which an enhancement program could be conducted.

1) An individual, private company or publicly funded company could conduct a vertically integrated enhancement program, i.e. establish a hatchery, seed a seabed area to which he/she/the company had exclusive access rights, and sole management and harvest rights.
2) A fishery-based consortium or cooperative could establish or contract out to a hatchery for spat production, obtain exclusive usage rights to a seabed area, seed, manage and monitor scallops in this area, then manage a harvest operation under their own stewardship and management.
3) The fishery could collectively contract out to a private hatchery, arrange to have the area seeded and monitoring under some form of company structure, then have a harvest strategy involving the whole fishery, with a levy on catches being used to recover the costs of enhancement.

There are an infinite number of permutations and combinations of these scenarios. We believe the third is impractical for management and cost recovery in the Queensland fishery (but not necessarily so in Western Australia), and will flesh out the first two.

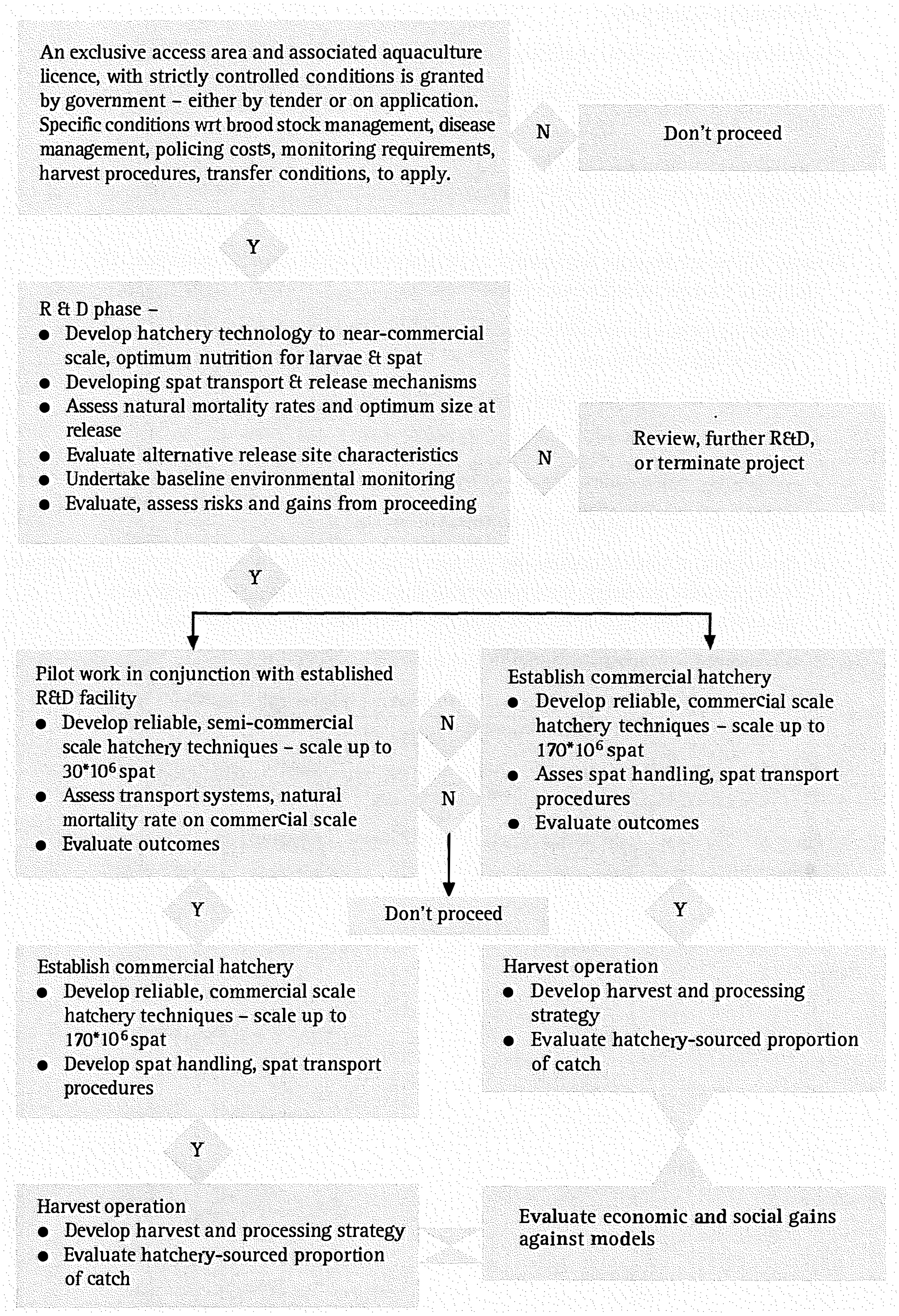
The first scenario basically describes what is happening in Western Australia at this time. The Western Australian Fisheries Department has allocated 'exclusive use' areas to a private company for experimental seeding and enhancement research. The company has established its own hatchery and is attempting to rear appreciable quantities of saucer scallops to a size large enough for experimental release. The company is using its own resources for hatchery research and development, and is treating its operations and findings largely as commercial in confidence.

The Western Australian government and the private venture company have used a site selection process that:

- avoids existing fishing grounds as much as possible;
- requires identification of clean sandy bottom, not far from existing scallop beds;
- minimises opposition from local cray fishers;
- uses a site on which there is historic evidence of saucer scallops settlement, with good survival and growth rates;
- allows for spat to be transported without being too expensive or logistically difficult to be practical;
- involves positive interaction with marine conservation agencies;
- avoids the need for buoys or physical markers.

The venture company has been issued with a conventional aquaculture licence issued under the authority of the Western Australian Fish Resources Management Act of 1994. The licence effectively allows the licence holder exclusive use of a 4’* 4’ (ca 50 km^2) area for experimental and commercial restocking. The licence contains very specific conditions relating to surveys of natural populations and monitoring survival and population levels of hatchery reared scallops. Scallop taken during harvest operations and not originating from hatchery-reared spat are to be sold to the benefit of the Crown.

A business operation based upon a single business entity, with associated business decision rules, could be based upon the following scenario.



The second scenario (fishery-based consortium or cooperative) could again be set up under many operational structures. We have attempted to describe two – conservative and high risk.

The basis for a business operation includes:

1) obtaining government approval to establish an enhancement operation, and to obtain in-principal agreement for the exclusive use of a re-seeding area.
2) identifying and gazetting an exclusive use re-seeding area.
3) identifying and reserving a prospective hatchery site, and obtaining local authorisations to establish a hatchery.
4) identifying critical R&D requirements for the needs of an enhancement operation.
5) initiating and progressing a R&D program, based upon issues identified in Sections 5.1 and 5.2, above.
6) having government agree to facilitate the establishment of a scallop enhancement management company, and set up a strategic plan/process for future evaluation and development.
7) establishing a company framework to progress the enhancement operation. The company's terms of reference should include:
    - establishment of a detailed operational plan and budget to progress enhancement in the exclusive access area;
    - development of an R&D strategy, plan and budget;
    - obtaining funds to meet budget requirements;
    - developing catch-sharing, cost-recovery and profit-sharing protocols;
    - taking over responsibility for ongoing pilot work;
    - developing a staff structure and infrastructure program, that will develop and operate a commercial hatchery, monitor seeded spat, develop harvest management procedures and operations and progress other research requirements;
    - developing protocols for policing the exclusive access area;
    - maintaining effective working relationships with government, other sectors of the scallop industry and environmental management agencies;
    - pursuing the long term requirements of a scallop industry with stable production levels, based to some degree on enhancement.
8) Have the company take up its charter of operations, and commence a hatchery and enhancement operation.

These procedures can be summarised as:

Management, governance	R & D
Government agrees with concept, organise exclusive access area under legislation	Egg capacity, handling of broodstock
Develop budget & operational plan	Larval rearing a) Nutrition @ experimental level b) Scaling up – resources, logistics etc. in holding larvae at large scale, optimising nutrition for optimum growth & survival
Promote concept to industry, call for expressions of interest	Identify settlement cues to accelerate and maintain settlement
Establish management company, board of directors, financial management structure, obtain funding from investors, granting / development agencies	Handling technology to settle, feed and handle very large numbers (>50 000 000) of settled larvae. What is appropriate feeding regime for optimal growth?
Develop commercial hatchery, employ staff, scale up to commercial scale operations	Site selection, transport of spat or juveniles, re-seeding protocols
Deployment, monitoring, enforcement, compliance	Survival and growth of seeded scallops as a function of size at release, density and numbers
Harvesting	Develop and instigate basic environmental monitoring procedures

We envisaged time lines based around those in Table 5.15.

Table 5.15 Potential time lines for a saucer scallop enhancement operation

Year	Organisational framework	Process	R&D Phase	Commercial hatchery	
				LOW RISK	HIGH RISK
Y 1	1) Government commitment 2) Exclusive access area concept signed off	1) FRDC feasibility study complete 2) Operating plan and budget agreed to.	Develop hatchery technology		
Y 2	Extension program, promote concept to industry	1) Operating company established – mostly private, some govt. advisory role, but to be phased out.	Ditto, studies on seeding survival as a function of handling techniques, size at release		Commence land purchase and infrastructure development
Y 3			Capacity to release 2-3 $*10^6$ spat on an experimental basis, in a 1 km^2 area, plan and conduct development plan		Hatchery developed and operating
Y 4			Harvest, evaluate	Commence land purchase and infrastructure development Release 40 $*$ 10^6 spat into 12 km^2 re-seeding area	
Y 5				Hatchery developed and operating	Harvest, release 40 $*$ 10^6 spat into 12 km^2 re-seeding area
Y 6				Release 40 $*$ 10^6 spat into 12 km^2 re-seeding area	Harvest, release 40 $*$ 10^6 spat into 12 km^2 re-seeding area

The potential financial risks and threats to this procedure and time lines include:

- hatchery technology not developing, or taking longer to develop than planned;
- predation and natural mortality rates being much greater than modelled;
- investors not prepared to risk, or commit because of extended lead time prior to returns coming on stream;
- government approvals process being too complex to accommodate investors;
- failure to develop agreed organisational and company structures and management;
- government taking excessive access and/or management fees;
- theft/non-compliance in exclusive access areas;
- issues of scale - how to handle a growth scale beyond our original 100 tonnes of meat scenario, particularly in relation to market issues and environmental politics.

6 Site selection and governance of marine ranching and enhancement operations in Queensland and Western Australia

A marine ranching or enhancement operation using saucer scallops requires two sites – one for a hatchery and the second, a seabed location, at which re-seeding can take place.

6.1 Hatchery sites

Potential hatchery sites have one over-reaching requirement – access to clean, oceanic seawater, preferably drawn from some depth, typically during the winter and spring spawning (but spring-summer in southern waters of Western Australia) and early nursery phase. Significant secondary considerations include access to power, fresh water, transport capacity to move scallop spat from the hatchery/nursery to the re-seeding site, and industrial infrastructure. There is some evidence from Chile (see Section 3.3) that a hatchery should not be constructed in the immediate vicinity of a culture site to reduce disease transmission risks. While there are no hard data on temperature regimes within which saucer scallops will breed, their natural spawning occurs at a time when water temperatures range between 17° and 25°C (Dredge 1981). Siting a hatchery in a location where this temperature regime occurs naturally during the relevant spawning season should contribute to successful hatchery operations.

We have modelled the economic costs of a hatchery using a site area of approximately one hectare. Locating appropriate sites of this size that meet the identified constraints presents some challenges, particularly in Queensland. Almost all of the coastal development and infrastructure along the Queensland coast between 20°S and 25°S has developed in the immediate vicinity of estuaries. Water quality in the immediate vicinity of these towns and cities may not be good enough to support an effective shellfish hatchery. Sites with access to both oceanic water and local infrastructure are confined to coastal areas south of Bundaberg and the coastal islands to the east of Gladstone. Some of the area to the south of Bundaberg abuts a coastal marine park, which may complicate water access and discharge approvals. There are numerous locations between Bundaberg and Gladstone that meet water quality criteria, but which have site deficiencies, largely through remoteness and consequent lack of access to electricity and support infrastructure.

Availability of hatchery sites in Western Australia is constrained by access to infrastructure rather than water quality. The requirement for power, staff accommodation, fresh water, repair facilities and construction capacity restricts hatchery site selection to the immediate vicinity of coastal townships such as Geraldton, Denham and Carnarvon.

6.2 Enhancement sites

Location of an enhancement or marine ranching operation using saucer scallops will be restricted by the species' natural distribution, by potential interaction with existing fishing and other marine industries and by conservation-related issues.

While saucer scallops can be distributed over a considerable area – between about 15°S and 35°S on both the eastern Australian and Western Australian coasts – their consistent distribution lies within 24°S and 32°S in Western Australia and 22°S and 25°S in Queensland. There are consistent but undocumented reports of scallops settling in areas outside this core distributional area that fail to survive in some years. We believe that attempting enhancement work outside the core distribution increases the risk of operational failure. This implies that a marine ranching or enhancement operation should be confined to the area between Yeppoon and Hervey Bay in Queensland waters, and between Shark Bay and Freemantle in Western Australia. While the species has been recorded from depths of 15–60 m, most catches are taken between 20 and 50 m. We suspect that an enhancement operation is more likely to succeed if conducted in this depth range. One downside about such depth constraints, however, is that direct observation and monitoring by divers is limited in depths greater than 20 m.

In the models we have described above, we have focused upon marine ranching operations that have exclusive access or usage of an area for enhancement work – i.e. the operation is not conducted for an entire fishery. Use of an exclusive access area implies exclusion of other trawlers. Western Australian authorities have dealt with the potential conflict associated with such a move by authorising a marine ranching operation in a location normally closed to trawling. There are extensive areas between 24°S and 32°S that meet this criterion in Western Australian waters. In Queensland, which has traditionally had a much more open approach to trawl grounds, the only way we can envisage minimising conflict is by allowing marine ranching in locations that have intermittently supported scallop beds, but which are outside major and consistent fishing grounds. This limitation, in conjunction with marine conservation issues (below), effectively constrains an enhancement operation to the western side of Hervey Bay, offshore from Baffle Creek to about Woodgate, i.e. in the area bounded by approximately 24°20'S 152°20'E, 24°20'S 152°45'E, 25°10'S 152°35'E, 25°10'S 152°50'E.

Conservation issues present the largest challenge and restriction on access sites for enhancement in Queensland waters. Current philosophy within the Great Barrier Reef Marine Park Authority is clearly unsupportive of enhancement. Whether this philosophy will change with time remains to be seen. However, under the current regime, marine ranching and enhancement are unlikely in an area north of 24°20'S, the southern boundary of the Great Barrier Reef Marine Park, in Queensland. The existence of a State Marine Park and associated whale watching industry in the eastern part of Hervey Bay does not preclude a marine ranching operation in the area, but appropriate authorisation would be required by the State's Environmental Protection Agency. Western Australian fisheries authorities do not appear to have such constraints to deal with when considering potential marine ranching areas their State waters, and may have the option of developing a fishery-wide enhancement operation, given the restricted access to fisheries in that State.

The balancing factor in a social equation is the very strong support for this concept from local authorities and agencies that are involved with social welfare and regional employment. Projects of the type we have discussed have the potential to generate considerable social benefits in the form of employment for unskilled workers in areas where unemployment levels are exceptionally high.

Enhancement and marine ranching operations, if undertaken, will occur within the legislative framework of the State and Commonwealth. There are a number of statutes that could impact on the successful implementation of an enhancement operation based on saucer scallops.

The primary authority for enhancement and subsequent harvesting lies within the framework of the *Queensland Fisheries Act (1994)* and the *Western Australian Fish Resources Management Act (1994).*

An enhancement or marine ranching operation could be conducted in, and on, an area of seabed set aside under some form of lease or seabed tenure for exclusive use by the operation's venturers. This would require the development of a lease by the respective State departments that administer land tenure. It is highly probable that such a form of tenure would trigger Native Title legislative requirements, and quite possible that the proposed enhancement project could lie within an area already subject to Native Title claim. Clarifying the administrative and legal issues associated with such claims could complicate and delay exclusive use of seabed for a considerable period of time.

The alternative legal framework for operating an enhancement or marine ranching operation involves the granting of an aquaculture authority under the terms of the respective states' fisheries legislation, and implementing complementary regulations, again under fisheries legislation. This involves the issue of an aquaculture licence or licences to permit capture and retention of broodstock and release of scallop seed into a given designated area. The licence would contain a series of conditions relating to harvest and monitoring requirements as required by the respective State authorities. Implementation of a parallel regulation that prohibited trawlers access to the marine ranch area would be required in Queensland, but not necessarily in Western Australia. Recent advice suggests that even this procedure will face legal obstacles in Queensland, as the State's Trawl Management Plan does not appear to empower the fishery's managers to close potential or existing trawl grounds for the purpose of marine ranching. The suggested methods for dealing with this impasse include amending the State's Trawl Management Plan or development of a specific Aquaculture Management Plan for marine ranching. Either of these options would take considerable time and effort to implement.

A precedent for appropriate regulation already exists in Western Australia, where a regulated area has been designated for saucer scallop marine ranching. This exclusive access area can be harvested only by the permit holder under the conditions of the permit, which include a series of monitoring requirements and procedures associated with distinguishing hatchery-reared from naturally spawned and settled scallops. The simplicity of this process reflects a basic tenet of W.A. fisheries legislation, in which there is a philosophy of defining areas than can be trawled rather than those that cannot. This concept means that exclusive access enhancement areas are unlikely to have negative impacts on other sectors of the fishing industry.

The situation is somewhat different in Queensland, partly through legislative structure and partly through an historic acceptance that areas of the seabed can be trawled unless specifically closed. Given the nature of Queensland's trawl fishery (large fleet, all vessels entitled to fish for scallops), history suggests that policing a marine ranching area (if legal mechanisms can be found to develop such an entity) will be a significant issue and cost to the venturers. Queensland has instituted a series of rotational 10' by 10' closures that act as broodstock preservation areas. These closures are strongly supported by a large majority of scallop fishers, but still have been poached on a regular basis. Policing of the closures is one of the most expensive activities undertaken by Queensland Boating and Fisheries Patrol. It is not difficult to anticipate that similar problems could occur in a dedicated marine ranching area.

While marine ranching and enhancement could be conducted under the auspices of State fisheries legislation, there are well-established conventions for consultation with other government agencies whose brief and legislation may be peripherally related to marine ranching and enhancement. These agencies include State and Commonwealth environmental management agencies, which would seek assurance that an enhancement operation would not impact upon rare, threatened or endangered species, or specific marine habitats. It is conceivable that Environment Australia's Marine Section (Environment Protection Group) may be involved in an enhancement operation if there were any proposals to place any form of aquaculture furniture in the marine ranching area. State marine safety and marine transport authorities may seek a right of comment in relation to marine safety issues.

7 Potential enhancement and culture methodologies, feasibility and benefits *(Pecten fumatus)*

7.1 Background

Pecten spp. and *Pecten*-like scallops have been the basis of scallop culture around the world. Culture of *Pecten* has been undertaken using a wide range of procedures around the world (see Section 3). Most *Pecten* culture systems are based on two general methods. One involves collecting spat, usually through the process of deploying spat collection bags in appropriate areas of the sea, but sometimes by rearing spat in hatcheries, and rearing these spat through to harvest in hanging cages or on long lines. Alternatively, spat can be on-grown for a period of 3–6 months in collection bags or hanging cage culture (intermediate culture) and then directly re-seeded onto the sea bed for subsequent recapture using conventional fishing technology.

7.2 Identify key operational procedures and operational / biotechnological bottlenecks for enhancement (Objective 1)

7.2.1 Spat collection and supply

Spat can be obtained from hatcheries or from open-water collection. Consistent supply of *P. fumatus* spat from hatcheries and open water spat collection has been a major constraint to the Tasmanian Scallop Pty Ltd. operation based at Triabunna. Limitations on open water spat collection are hardly surprising, given the apparently depressed state of the wild population in this area. Pilot spat catching operations conducted in Port Phillip Bay during 1999 and 2000 have given surprisingly high numbers of scallop spat (average of 1000 spat per bag), again given the apparently depressed level of parent stock (Mercer pers. com.). While this result is encouraging, the high incidence of exotic species in Port Phillip Bay, and the capacity of these exotics to settle in scallop spat bags means that scallop spat collected in Port Phillip Bay should not be translocated without a considerable cleaning and monitoring process being undertaken.

Hatchery-based sourcing of spat is feasible for *P. fumatus*, as the experimental technology is well established (see Heasman *et al.* 1998 and associated publications). The costs of basing an enhancement or culture operation on hatchery-reared spat is intuitively less attractive than for saucer scallops, *Amusium balloti*, given the differences in price and growout times.

Collection of spat from the wild supports the majority of scallop aquaculture and mariculture operations around the world. Successful wild spat collection requires a number of key requirements including:

- consistent existence of scallop broodstock;
- environmental conditions which are consistent with synchronous spawning, and effective spawning on at least an annual basis;
- oceanographic conditions which retain larvae in discrete areas, through a combination of ocean eddies or embayment;
- suitable temperature regime for the species concerned;
- suitable bacteria and algal levels for optimal larval growth;

- clean substrate for settlement;
- high salinity.

The collection of scallop spat from the wild involves the deployment of spat bags to provide a substrate onto which scallop larvae can settle and attach. The spat bags (40 x 80 cm) are designed with a mesh size of 2–6 mm which allows the larvae to pass into the bag, the larvae then settle on the internal mesh (netron). The larvae attach to the netron by laying down a series of byssus threads. The scallop larvae metamorphose and grow from 250µ to 6–12 mm over the next 3–4 months before releasing from the netron by separating the byssus threads from the byssal gland. The scallops that have settled on the inside of the bag and on the netron, now defined as spat, are retained in the bag due to the small mesh size. Most of the scallop larvae that settle and grow on the outside of the spat bag are lost to the seabed or predators, although some may remain attached and are recovered when the bags are sorted. Catch rates per spat bag vary greatly, with catch rates above 400 per bag typically being sufficient to support an economically viable operation.

The bags are hung on droppers, which are attached to a horizontal longline. The number of bags per dropper depends on the available depth. Generally, 10–25 bags are hung per dropper with the droppers spaced 1–2 m apart on the longline. The depth of spat bag deployment is critical for a successful catch. Scallop larvae usually settle below 10 m with catch rates increasing with increasing depth. It is recommended that local trials be carried out to determine optimal collector depth placement. Larval surveys in Tasmania have shown that larvae are found at 12–20 m below the surface and settle out between 22 and 34 m (Young, McLoughlin & Martin 1991).

Deployment timing is crucial for successful spat catching. Scallop larvae require a clean surface for attachment. 'Once in the water a collector (spat bag) will fish effectively for a short period. In temperate waters this is 10 days but in warmer areas it will be less' (Hardy 1992). To optimise timing of deployment it is necessary to monitor the scallop larvae in the water column. Through monitoring the larval growth an optimal deployment period can be calculated and farmers can significantly improve reliability and quantity of catch. 'The Japanese deploy their collector bags when over 50% of the scallop larvae in the water column are over 200µ in size. Scientists are employed on a full time basis to compile this kind of information….' (Hardy 1992). The Challenger operation in New Zealand uses a similar larval monitoring regime to the Japanese system with good success. Initially the New Zealand operation was able to catch reliable numbers of scallop spat without larval monitoring. The company instituted larval monitoring after a significant failure to catch scallops in a season of delayed spawning to ensure continued spat supply over future seasons.

Hatchery production may be needed in the absence of reliable sources of spat from open water sources.

7.2.2 Hatchery production for re-seeding

There has been significant research in NSW on the development of *P. fumatus* spat production techniques. These techniques were developed through a series of FRDC projects (Heasman *et al.*, 1995; Heasman *et al.*, 1998). With over four million spat produced during these projects the techniques are now considered reliable and efficient. It is very important to be aware that the scaling up of any research work to commercial production is an extremely difficult stage and is an area where many aquaculture operations fail. Any such attempts must be well funded and have sufficient time to overcome the difficulties in production that will occur.

Key hatchery requirements

For successful commercial hatchery production to occur a number of specific requirements are needed:

- Available coastal land for hatchery site
- Access to high quality seawater
- No freshwater influence
- Sufficient depth (usually >20 m)
- Limited drift weed
- Experienced staff
- Services; power, telephone, freshwater
- Reliable culture techniques.

The availability of coastal land is limited and often expensive particularly when located close to areas of deep water. It is, however, imperative that the site be located in close proximity to a supply of high quality sea water. Failure to do so will ultimately result in failure to achieve reliable commercial success. Many hatcheries, particularly government research hatcheries are situated with other priorities in mind and/or the species originally intended for culture are either intertidal or estuarine organisms. These intertidal and estuarine organisms are generally more robust in their ability to endure varying water quality. Scallops are generally found where water quality is excellent and the physical environment is stable. They consequently have difficulty coping with varying water quality. The experience of Bourne *et al.* (1989) suggests that seawater intakes should be 20 m below the surface. Hardy (1992) also suggests twenty metres below the surface for seawater intake placement for the culture of scallops. Drift weed, fish, octopus and fouling organisms all have the potential to interrupt seawater supply. The capacity to locate pipe intakes above the seabed by 1–2 m with suitable screening systems will dramatically improve reliability and quality of seawater.

There are few successful bivalve hatcheries in Australia and personnel with experience and capacity to rear shellfish are sparse and in demand. It is thus critical that any commercial development must factor in time to train and develop experienced staff. Even with reliable techniques already developed by research, staff will still take considerable time to apply them to any new hatchery system.

7.2.3 Hanging cage culture

Hanging cage culture involves the grading and transfer of spat from either a hatchery or spat collection bags to pearl or lantern nets of 4.5–9 mm rachel mesh, with stocking density of 20–50 scallops per layer. Pearl nets are hung in vertical arrays of about 10–15, and are set out on a buoyed sub surface long lines (Figures 4.3, 4.4). The vertical arrays of lantern nets and pearl nets are spaced between 0.5–1 m apart. Longlines range from 100–400 m in length with 4-ton concrete anchors at either end. A series of smaller counter weights along its length allow the longline to be held at a predetermined height above the bottom. Flotation of the longlines is achieved by a row of buoys. These buoys are held under the surface by the series of counter weights on the longline. All flotation must be pressure tolerant and have a very low failure rating. Spacing is critical to eliminate longlines crossing over with resulting in loss of product. The depth of the site, currents and prevailing winds determines longline spacing.

There are a number of technical and logistic difficulties associated with hanging cage culture being used to rear *Pecten*. These include:

- adequate spat supply;

- reduction of growth through cage being fouled by algae, bivalves, ascidians, hydroids and biological waste;
- problems associated with cleaning up such fouling;
- the very high labour demands required for cage culture (dealing with fouling, thinning out, changing nets, re-buoying long lines);
- difficult and expensive logistics associated with anchoring cages in the relatively exposed waters where *Pecten* occurs naturally;
- probable opposition to the use of hanging cage culture by conservation interests;
- lack of culture sites with suitable environmental (temperature, salinity, depth, wave height, current, feed levels) requirements.

7.2.4 Fouling

Fouling can be dealt with by the use of net washers. Net washers use high pressure and high volume water flow to rapidly remove fouling from the nets and, in some cases, the scallops. Units can be both land-based or mounted on board the vessel. Biological waste can be either contained in land-based settlement ponds or through sea-base operations on the farm site. This practice is currently carried out at a commercial level at number of mussel farming sites in Victoria. Dive surveys using video cameras have not shown any obvious changes to the area under or between the farms (Mercer pers. com.), but there will be a requirement for more detailed chemical and biological assessment if on-site treatment is used to deal with fouling. Generally the larger the culture operation the greater the reliance on land based cleaning. Antifouling compounds commercialised by Wattyl Pty Ltd have been effective in the N.S.W. (FRDC funded) scallop culture program as well as in the pearling industry. Further developments in the field of specific antifouling compounds may lead to significant cost saving in cage and hanging culture operations rearing shellfish.

7.2.5 Labour costs

Many aquaculture operations such as scallop culture require high labour inputs. To reduce labour costs companies employ small numbers of highly trained farm managers and employing seasonally unskilled staff to assist during periods of high labour demand. These high labour requirements usually occur 2–3 times per annum and last from 2–6 weeks. These costs are unavoidable and may be a critical factor for the success or otherwise of an enhancement operation.

7.2.6 Site selection

Hanging culture of scallops in areas of high wave action is technically difficult and often biologically impossible. Consistent bad weather will obviously reduce access time and limit regular site inspections and capacity to maintain equipment. Excessive sea and swell conditions can lead to high scallop mortality caused by vibration and movement even though the culture system is sub-surface. Areas of high swell height are best suited to re-seeding onto the bottom.

The most suitable sites for hanging culture of scallops have:

- a depth greater than 20 m. Depth of longlines can be varied to avoid fouling;
- stable temperature regimes, with water temperature not exceeding ca. 21°C;
- relatively flat bottom topography for ease of anchoring;
- good water circulation to supply food (< 3/4 knot);

- maximum wave height less than 1.5 m to enable ease of access;
- high stable salinity to reduce stress on scallops;
- limited site closure from algal or bacteria contamination for market reliability;
- limited fouling of predators such as starfish, crabs and flatworms
- stable temperature profile. Short term fluctuations in temperature can be stressful for scallops;
- are in enclosed or protected embayment which are not exposed to strong winds.

Sites with these characteristics are extremely difficult to locate on the southern Australian coast.

7.2.7 Bottom re-seeding (enhancement or marine ranching)

Technical procedures

The alternative to hanging cage culture involves the creation of artificial beds of scallops by collecting spat from the wild or a hatchery and deploying onto the seabed. These scallops are seeded at a size at which natural mortality levels do not present a threat to the economic viability of the operation.

Successful re-seeding is reliant upon a reliable supply of scallop seed. The largest and most successful re-seeding programs have occurred in Japan, France and New Zealand. The Japanese and New Zealand operations relying upon collection of spat from the wild whilst France operates the only known commercial re-seeding program dependent upon hatchery-produced spat.

Optimising size of scallop for re-seeding is a balance between the costs of ongrowing and natural mortality rates, which in turn depend upon factors such as predation pressure, size of predators, predator seasonality, seasonal food availability, growth rate, water temperature, competing organisms, numbers of spat deployed and area of re-seeding. As these facts vary greatly for each re-seeding program it often take years to refine the optimal re-seeding strategy and obtain consistent output levels. Each re-seeding operation is different as can be seen below in Table 7.1.

Table 7.1 Key technical variables for re-seeding

	Re-seeding size (mm)	Intermediate culture phase	Re-seeding quantity per year	Scallop supply	Age at harvest -years	Predator removal
Japan (1)	30–40	Yes	1. billion	Wild	2–4	Yes
New Zealand (2)	20–30	No	>250-million ?	Wild	2–3	Yes
France (3)	?	Yes	?	Hatchery	3–4	?

Re-seeded temperate scallops generally take 1.5 to 3 years to reach harvest size. It is therefore necessary to divide the culture grounds into several sections for rotational harvest. Grounds to re-seed have usually firm bottoms with fine gravel or sandy mud. These grounds are usually greater than 10 m in depth to avoid the effects of wave action. Re-seeding densities are dependent on size but are generally from 4–6 scallops per m^2. Commercial scallop densities at harvest range from 0.5–1.5 m^2.

The Australian experience

Attempts at re-seeding *P. fumatus* in Australia have met with limited success to this time (see Section 2). Commercial re-seeding trials in Tasmania, whilst showing initial success, have been unable to produce reliable production even after significant financial commitment (O'Sullivan 2000). Small scale re-seeding trials at Jervis Bay in NSW were unsuccessful because of heavy predation (Heasman *et al.*, 1998).

Transport phase

The handling of scallop spat is critical to the success of any re-seeding operation. Scallop spat if handled correctly can survive well, it is however important to follow strict protocols:

- Carry out grading quickly
- Keep spat cool
- Keep spat shaded
- Always sort spat in flowing seawater
- Keep oxygen level in water high
- Sorting at sea is best due to lower air temperature
- Keep spat in flowing seawater at all times
- Do not crowd spat for extended periods.

Where scallop spat are supplied from the wild they are generally re-seeded within a local area that is readily accessible by a fast boat. Wild spat can also be relocated to shore-based facilities for resorting and then shipped by refrigerated truck to other areas of the coast and then re-seeded from boats. This technique is widely used in Japan with great success; it does however rely on the spat being robust enough to survive the handling. *Pecten* spat generally are quite hardy when larger than about 8 mm in size, although the larger they are the higher their survival.

An enhancement operation based upon hatchery-reared scallops will require a transport phase, in which juveniles are transported from the hatchery to the growout site. While this seems to be a simple procedure, it has the potential to offer some logistic complexities when considered in the context of moving many millions of scallops. Hatchery based production of scallops requires moving spat as soon as possible after settlement or on growing to a larger size. The former may be more cost effective whereas the latter if possible produces more robust seed but at a greater cost.

Micro spat transfer

A scallop spat production system developed by Heasman *et al.* (1998) for *P. fumatus* requires that the spat be allowed to attach to fine mesh. This mesh with attached spat (0.5–1 mm in size) is then cut into sections and placed into spat bags similar to those used in wild spat collection. Results showed that movement of this sized spat requires shipping in seawater, or, if the spat is not in seawater, very short shipment time. The key limitation with this system is the need to transport the fine mesh with spat attached in seawater. The fragile nature of 0.5–1 mm spat requires the development of commercial transport tanks.

The transfer of micro spat has the benefits that the period of time that the spat are held and fed in an expensive hatchery is limited and if they are then placed at a good site then the natural environment looks after the seed at very little cost. With a production period of only four weeks this allows the hatchery to produce many batches. This allows for some batch failures while producing large quantities. This process of producing large quantities of bivalve larvae for settlement onto substrate (cultch) followed by deployment into the marine environment after only a few days is the basis for a substantial shellfish industry in Western North America. The process is commercially used for production of Pacific oysters, manilla clams, scallops and blue mussels.

To date there has been no commercial trials using this method in Australia, and considerable work will be needed to evaluate the advantages of handling and releasing very small spat against the high natural mortality such small spat may suffer. If large quantities of spat are to be reliable produced, transport logistics will need appreciable study.

Optimal requirements for a successful transport phase include:

- hatchery located at optimal site;
- close proximity of hatchery to jetty for rapid transfer of spat to vessel;
- suitable transport vehicle with seawater tank;
- access to vessels with wet wells for shipment to site;
- short steaming time to suitable intermediate culture site.

Although these requirements seem achievable, most scallop culture operations need government support to enable these requirements to be met.

Macro spat transfer

Hatcheries producing scallops have often held spat to a size of 20–30 mm, to reduce subsequent predation. The production of this larger spat is much more expensive, as it requires:

- larger and more prolonged algal production
- larger site for ponds or tanks
- high seawater requirements
- high labour and capital inputs.

The extended period of intensive culture runs the risk of equipment failure and has often resulted in significant mortalities due to lack of suitable feed and water requirements. Reasons for producing larger spat include:

- retention in mesh bags or nets when deployed in field
- buyers preference
- the need for reliable size and numbers for research work
- lack of access to suitable nursery site
- absence of a byssus attachment phase.

Work by Heasman *et al.* (1998) has shown that an extended period of intensive culture can be success at the pilot scale. Their work on the micro spat transfer shows a very cost effective way of achieving the numbers of spat necessary for re-seeding. Investigation and commercialisation of this area of culture is required.

Survival and growth of re-seeded scallop

Predation and survival of juvenile *P. fumatus* in a re-seeding operation remains a potential issue and threaten the viability of an enhancement operation. The experience of Cropp (1987) and Heasman *et al.* (1998) suggests that small-scale pilot releases have little value – either predators have to be saturated, controlled or temporarily excluded from stocked areas during the initial periods of re-seeding which may be for 3–4 months after settlement. Japanese re-seeding operations rely on predation controls, and the New Zealand enhancement operation referred to above also attempts to remove starfish from re-seeded beds.

One of the most significant issues to be addressed is that of size at release. The discussion above illustrates the reduction in cost attainable by releasing small spat. What is not clear, however, is the relative rates of predation between small and large spat. This information is critical to the economic evaluation of a re-seeding program using *P. fumatus*.

7.2.8 Identification of hatchery-reared scallops

Releasing hatchery or wild-caught scallops into an area suited to the species, and which may have previously have supported commercial densities of scallop, calls for differentiation between naturally settled animals and hatchery-reared stock. While we know of no any serious work on this issue in Australia, we do not believe that distinguishing hatchery reared and cultivated *P. fumatus* from naturally settled animals will present a major challenge, at least for spat released at 20–30 mm. We observed clear checkmarks on adult *Pecten novaezelandiae* that had been sourced from spat collectors in Golden Bay (Section 4), and were advised that cultivated scallops could be distinguished from naturally settled scallops with >90% accuracy. Distinguishing spat released at very small sizes (<10 mm) may be more difficult, and further work requiring chemical or genetic markers such as oxytetracycline, calcein or DNA micro-satellite markers may be needed to ‘tag’ hatchery reared scallops.

7.3 Identify financial, social and biological risks associated with enhancement and culture of scallops *(Pecten fumatus)* (Objective 2)

Any aquaculture development should achieve an overall improvement in the social and economic benefit of the community while being environmental sustainable. The financial risks associated with a program based on *Pecten fumatus* are largely dealt with in Section 7.4.

7.3.1 Social risks associated with hanging culture

The utilisation of the marine environment for recreational and commercial gain is increasing, and there is real or perceived competition for access to marine resources and space. Recreational and commercial fishing, aquaculture, marine eco tours, scuba diving, whale watching, bird watching, water sports, petro-chemical exploration and mining all have an impact. As a result both State and Federal Governments are undertaking processes that strategically plan the use of our oceans for the benefit of future generations. A strategic and balanced approach is needed to both allow environmental sustainable development and society’s needs for preservation.

Conservation-related issues are a major potential constraint to enhancement and hanging cage culture operations using *Amusium balloti*, particularly in Queensland. Conservation issues do not appear to have the same potential for generating controversy in the context of enhancement or hanging cage operations based on *Pecten fumatus*. This generalisation is subject to conservative practices in terms of handling spat and minimising the risk of transferring exotic species from areas such as Port Phillip Bay, when exotic invertebrates are becoming a major concern.

The development of any hanging culture operation requires the allotment of areas for culture. These areas are usually accessible by the general public and commercial enterprises. It is critical that any potential conflicts with these groups is recognised, addressed and resolved with solutions that are fair and equitable to the parties involved.

The annexation of crown waters for scallop hanging culture in marine areas has the potential to impact upon:

- recreational fishing
- commercial fishing operations
- commercial boat traffic
- eco-tours
- upland owners' visual amenity.

Public access to areas used by scallop farmers should still be accessible to the general public. Most boating craft can safely pass through a farm site due to the depth of equipment and the limited number of floats. A public information program on where to fish and where not to fish within the farm sites would assist fishers from loosing fishing gear yet still allowing them to utilise the farms as artificial reefs, thus offering some social benefits. Potential aquaculture zones would potentially become more popular for recreational fishing if the ECC recommendations for marine parks are implemented and previous popular reef areas become unavailable. Mussel farms in both Victoria and New Zealand are popular sites for fishing and it is likely that any new scallop farm sites will be used in the same way.

Visual pollution is often sited as a major concern with marine aquaculture. Scallop hanging culture causes little or no visual pollution. All culture equipment and longlines are sub-surface, usually 8–10 m below the surface. Each longline has two surface floats of 30 cm in diameter, which are placed at either end of the longline. This equates to 2.5 floats per hectare of scallop farm. These floats are usually dark in colour and can usually only be seen from 50–200 m depending on sea conditions. An additional four corner markers with flashing lights are required for navigation purposes to delineate the farm site. A consultative process on the development of Marine National Parks and of new aquaculture zones was initiated to ensure that these issues have been addressed in Victorian waters.

7.3.2 Biological risks associated with hanging culture

Key biological risks associated with hanging cage culture are identified in Blankenship and Leber's (1997) review.

These key biological issues that relate to hanging cage culture are:

- develop a species management plan
- use genetic resource management
- use health and disease management.

Species management plan (Port Phillip Bay)

The commercial fishery for *P. fumatus* in Port Phillip Bay was closed, for social reasons, in 1996. Continued surveys and assessments surveys show that scallop numbers are still at very low levels (Coleman pers. com.). It is, therefore, unlikely that the scallop dredge fishery will return to Port Phillip Bay in the foreseeable future. There is considerable interest in a dive fishery for scallops, though this is also unlikely to eventuate in the foreseeable future, given the low standing crop of scallops in Port Phillip Bay.

The end result of such management measures is that a re-seeding operation or marine ranching operation is unlikely to be approved in waters of Port Phillip Bay.

Hanging cage culture, on the other hand, does not seem to have the same level of social opposition, and may be a realistic option in the Bay (See Section 8). Given the absence of commercial scallop fisheries in the Bay, management plans do not have the same significance as would be the case if the resource was shared. A hanging cage culture operation would use a negligible proportion of larvae in the Bay, but in time may act as a stable source of scallop larvae and population enhancement, as has been observed in other parts of the world.

Port Phillip Bay hosts large numbers of exotic organisms, many of which are direct competitors with scallops, or are major predators. The existence of a scallop population in hanging culture, which is partially removed from the influence of exotic organisms, has the ability to help maintain the population of native scallops that may otherwise be under threat from exotics.

Environmental impacts

The most obvious environmental issue related to the success of *P. fumatus* culture is the relationship between environmental variables and *P. fumatus* population levels. The range of environmental variation the species can tolerate is not well documented. There are some data that suggest water temperatures above about 20°C are harmful or lethal to the species, and that such water temperatures may affect existing populations in some years in areas like Port Phillip Bay (Coleman pers. com.). The species is intolerant of reduced salinity, and may suffer higher than normal mortalities in years of heavy runoff in some coastal areas.

Any hanging cage operation will have some effect on the surrounding area. There is an obvious need to predict what may be affected and how it is affected, to assess potential impact and evaluate these potential risks. It is ultimately this risk assessment which will determine if the benefits are sufficient to warrant the risks taken. Finally, a monitoring program aimed at assessing the reality of predictions is needed.

Environmental impacts from marine aquaculture can be diverse.

These potential impacts include:

- changes to biodiversity
- nutrient changes from release of faecal matter and or uneaten food
- chemical by-products resulting from disease treatment
- litter from farming activities.

Any longline operation, whether it be mussel, scallop or oyster, will trigger a significant increase in biodiversity due to the increase of available substrate and three-dimensional structure. This increase in biodiversity causes fouling of equipment that has to be removed at 3–6 month intervals throughout the year. Fouling material is removed from the equipment either at sea or at a land-based operation. The effect on biodiversity to the seabed as a result of deposition from fouling organisms is often sited as a concern. The effects of such deposition on the surrounding seabed have not been addressed in any detail and is an area of research that needs to be addressed in any management plan. Anecdotal evidence suggests that the effects if any are minor and very short lived. Even if this is the case this effect should be quantified to alleviate any concerns within the wider community.

The release of faecal matter and or uneaten food deposited under farms can result in localised changes to biodiversity and nutrient inputs. Scallop culture, unlike finfish culture, takes its feed from the environment. There is no deposition of uneaten feed collecting under the farm. As scallops take their feed from the natural environment there will be a net reduction in nutrient loading, which could be of environmental benefit. This nutrient reduction is in accordance with the Victorian Environment Protection Authority policy of nutrient reduction in Port Phillip Bay. Faecal deposition under scallop farms has not been monitored in Australia. This deposition is unlikely to have an affect as stocking rates of scallop in hanging culture of $2/m^2$ of farm area is within the normal range of scallop abundance observed in the natural environment.

Chemicals are not used in scallop hanging culture. The extensive nature of scallop culture and the scallop's ability to filter out substances make the use of chemicals impractical and undesirable from a human health perspective. Biological antifouling compounds are being researched and developed, though this work has been focussing on compounds that work more as a physical barrier than a chemical inhibitor.

Litter from farming activities can come from biological fouling and lost farming equipment. The effects of washing fouling organisms from the nets on the benthos, if any, has yet to be quantified. However, preliminary visual surveys under mussel farms that carry out similar operations show minimal effects (Mercer pers. com.). The loss of floats and ropes from farms will be limited as any loss of equipment will result in scallops being placed on the bottom and exposed to predation by starfish, making the farm unprofitable.

Under the *Victorian Fisheries Act of 1995*, management plans will be implemented for each of the States' aquaculture zones. Part of these plans will require monitoring to be carried out. This will address the risks and concerns associated with the environmental effects of scallop culture.

Genetic protocols

With any aquaculture operation it is important that the culture operation does not distort the existing genetic structure of the population. This is not an appreciable risk for cage culture operations based on collection of wild scallop spat. The population that is under culture is likely to originate from a large cross section of the genetic pool, ensuring the genetic structure is not distorted. Grading of scallops during the culture cycle does occur. This variability in size of scallops is generally regarded as a result of the effect of food availability when in the spat bags. Scallop spat located close to the outside of the bag receive more water flow and achieve faster growth. The size grading is based on an environmental effects and not genetic selection.

Disease protocols

The development of a disease-monitoring regime is an important component for any scallop culture operation. Currently disease monitoring is carried out in shellfish when product is to be translocated between States, exported from Australia, when a disease outbreak occurs and in limited areas under a routine disease-monitoring program. There is limited funding for fish and shellfish health currently available at both the State and Federal level. The Tasmania Department of Primary Industries, Water and Environment has the expertise necessary to develop a disease-monitoring program and should be consulted if expertise is limited. Any disease program needs to abide by the OIE protocols (OIE Manual 2000) to meet current international standards. With changes to the European standards for shellfish importation requiring background disease monitoring, it is likely that an improvement in expertise and disease monitoring programs will take place.

Human health protocols

Australian Shellfish Quality Assurance Program

All shellfish cultured in Australia that are to be offered for human consumption must be produced under the standards of each State's Shellfish Quality Assurance Program. This program ensures that the levels of contamination from faecal bacteria and algal-derived toxins are at a level safe for human consumption. Each State maintains a shellfish quality assurance program, which is based on Australian Quarantine Inspection Service (AQIS) requirements. The AQUIS program is in turn based on the international and USFDA standards for shellfish. Any bivalve shellfish being exported from Australia must meet AQIS requirements to obtain export certification.

Scallops harvested from the wild in Australia have not required this certification whereas any scallops cultured in aquaculture operation may be required to meet these standards. This is essentially due to the potential location of aquaculture operations in coastal locations. These can potentially be affected by faecal contamination, where as most wild-caught scallops are in offshore that are not subject to such contamination. The potential for toxic algal contamination is still possible in offshore areas but this risk has not been regarded as high enough to be an issue in the past. In recent times there is increasing interest both nationally and internationally in ensuring that all shellfish both wild and cultured be monitored under a shellfish quality assurance program. The implications of this are substantial for both fisheries managers and the fishing industry. It is interesting to note that the New Zealand enhancement operation is able to carry out a substantial and cost-effective shellfish monitoring program due to its rotational harvesting protocol and a short harvesting season. The rotational harvesting strategy reduces the area to be monitored each harvest period and the short harvesting season helps reduce monitoring costs.

7.3.3 Social and biological risks associated with re-seeding and marine ranching

The concern and risks associated with re-seeding in Victoria are similar to those that exist in both Queensland and Western Australia, and have been discussed in some detail in Section 4.3.

There are, however, some issues that are peculiar to the Bass Strait population and fishery for *P. fumatus*. The natural population of *P. fumatus* is at an apparently very low level, the fishery is effectively closed through much of the species' distribution and there is considerable concern about possible recruitment overfishing. As a consequence, there is considerable local interest in an open water re-seeding and enhancement program in coastal and offshore waters of Bass Strait. At the same time, the fishery is not generating sufficient revenue to offer any realistic capacity to meet the costs of such an operation.

7.4 Undertake a preliminary feasibility study and cost benefit analysis for enhancement and culture of scallops (Objective 3)

We have undertaken preliminary modeling on the economic viability of two potential forms of scallop culture using *P. fumatus*.

The first is based on the concept of a hanging cage operation conducted in a 20 ha exclusive use site, and relying on spat collected from open water, using conventional spat collecting technology. The operation is based upon on collection of ca. 1000 settled spat per spatbag, which are then on-grown through intermediate culture (6 months) and lantern cages, to be harvested at 18 months. The project was modeled with a 20-year lifespan. Details of the operation are given in Appendix 2, in the Excel™ spreadsheet "*BaylonglineCulture.xls*".

The model predicts an annual production of approximately 27 tonnes of whole scallop following a two year phase-in operation. Annual revenue is predicted to be $269 000 and annual costs $183 000, i.e. production costs of $6.60/kg and revenue of $9.70/kg. Return to capital was estimated at 16.1%, Internal Rate of Return (IRR) was 18.7%, and Benefit:Cost (B:C) Ratio was 1.47.

The operation's profitability was relatively sensitive to labour cost input and price structure. The model incorporated two staff (a labourer and on-site supervisor) as the basis of its labour cost. The addition of one additional staff member, or 4000 hours of casual labour, reduced predicted returns by 50%. The model's price structure was based upon a mixed market approach incorporating sales of whole live scallop, half-shell scallop and fresh meat. A reduction in price of whole scallop (the principal market) by 20%, for example, reduced return to capital by about 60%.

This relative sensitivity is not surprising, given the relatively small scale of the project that has been modeled.

The model does, however, predict that a small-scale scallop enhancement operation that was able to collect ca. 1000 spat per spat collector and generate commercial production within 2–3 years of commencing operations would be economically viable.

The alternative proposal of using *P. fumatus* was based on an open water re-seeding (enhancement) operation, spat for which were derived from a commercial scale hatchery. Details of the hypothetical operation include:

- establishment of a hatchery at a capital cost of ca. $1 000 000 and annual operating costs in the order of $800 000, including opportunity and harvest costs;
- hatchery supply of 23 000 000 10 mm spat for re-seeding annually;
- harvest of seeded scallop at an age of approximately two years;
- production of ca 100 tonnes of scallop meats per annum, with a gross revenue of ca. $1.4m, but with production varied according to natural mortality rates;
- three year lead-in time between commitment of capital and production;
- re-seeding an area of ca. 9 km^2;
- project life span of 20 years.

The model used to evaluate this scenario was based on the equivalent scenario used to evaluate the feasibility of re-seeding *Amusium balloti* (See Section 5.4) and is included in Appendix 2 as "Lakes Entrance-revised.xls" and "Lakes Entrance-rough". The model "Lakes Entrance-rough" assumed varying amounts of scallops being harvested each year, at an age of 2 years, following the release of ca. 24 * 10^6 10 mm spat. Harvest was ca. 80% of available scallop. We know of no published information on natural mortality rates of *P. fumatus.* Published data on natural mortality rates of *Pecten*-like scallops does not offer a great deal of insight. Posgay (1979) gives an estimated value for M of 0.1 year^{1} (=.002 week^{-1}) for adult *Placopecten magellanicus* and Orensanz (1984) estimated M to range from 0.62, through 0.99, to 1.98 (year^{1}) (= 0.01, 0.02, 0.04 week^{1}) in three successive years for *Chlamys tehuelcha.* Given the uncertainty of natural mortality rates for *P. fumatus*, particularly during the earlier stages of the species' life cycle, we have not attempted to estimate 'best guess' economic return from a re-seeding operation. Rather, we have set up a basic economic model that assumes constant cost of spat production in a hatchery environment, but varies natural mortality rates (M) through the species' life cycle. The models then return a range of values for economic parameters under each set of values for M. Values for M and corresponding economic results are summarised in Table 7.2.

Table 7.2 Predicted returns from a hatchery-based open water re-seeding operation using *Pecten fumatus* with varying estimates for natural mortality rates (Size of scallops in millimetres, duration of life-cycle phase in weeks).

Scenario				I.R.R.	B:C	Time to attain +ve (discounted) cash flow (years)
Size (mm)/ time(weeks)	10–30 /25	30–50 /25	50–90 /50			
M (week^{-1})	0.030	0.004	0.002	28%	1.5	7
	0.030	0.006	0.003	24%	1.4	7
	0.030	0.008	0.004	19%	1.3	8
	0.030	0.010	0.005	14%	1.1	11
	0.030	0.012	0.006	<0	<1	>20

The operation's financial viability fails when weekly instantaneous natural mortality rates are forced to a level of 0.030 for scallops in the size range 10–30 mm (25 weeks), 0.012 for scallops of size 30–50 mm (25 weeks) and 0.006 for scallops in the size range 50–90 mm (50 weeks).

It is possible to use a range of size/time ranges and natural mortality estimates to develop scenarios, but the process basically demonstrates the sensitivity of financial success to natural mortality rates, and the very considerable uncertainty we have about best estimates of natural mortality rates for *P. fumatus*.

We suggest there is considerable financial risk in commencing an enhancement operation without undertaking an initial assessment and research on natural mortality rates of *P. fumatus* at different life cycle stages and varying densities.

7.5 Development of a business plan for conducting a financially viable and ecologically sustainable enhancement scallop culture operation. (Objective 4)

7.5.1 Business plan for hanging culture

The ability to successfully develop a scallop hanging culture operation relies on a considerable number of variables.

These include:

- access to suitable sites
- the ability to collect scallop spat reliable
- a shellfish quality assurance program
- expertise in scallop culture
- capital infrastructure
- venture capital
- profitability.

Within Victoria's Port Phillip Bay there are a number of areas that have considerable potential for scallop culture. The discretion for using these areas for scallop culture ultimately lies with Ministers of the State Government and their delegates. Their decisions may be influenced by recommendations contained with the ECC Final Report (ECC 2000). Should the development of these aquaculture areas be approved then the major constraint to scallop aquaculture will be lifted. Without these areas being approved for shellfish culture it is highly unlikely that scallop aquaculture based on longline technology will ever succeed in Victorian waters.

Access to scallop spat from the wild is a significant asset to any scallop culture operation, however, the ability to produce spat via a hatchery is always an option. Should the ability to catch spat from the wild be variable it would still allow farmers, who have established themselves as mussel growers in the new aquaculture areas, to trial small-scale commercial production of scallops and determine its potential profitability. It is also likely that as the industry grows the reliance on wild spat may diminish in preference to a reliable supply from a hatchery and its ability to supply on a year round basis. This transition from wild spat dependence to hatchery supply has occurred in other shellfish industries around the world as the industry matures.

The Victorian Shellfish Quality Assurance Program would be able to encompass any new areas for shellfish culture under its current sampling regime. Any new area would increase the cost to the managers of the program, however the farmers themselves are required as part of their licence conditions to contribute up to 30% of the total costs of the program. The ability to export from these new areas could be delayed from 1-2 years due to the requirement for background sampling to rate the area under the Clean Waters Policy contained within the VSQAP.

Given there is a commercial mussel industry already working in Port Phillip Bay and that the Bay was once a substantial producer of scallops from dredging, much of the infrastructure needed for developing a scallop aquaculture industry is already in place. There are a number of piers that could be easily upgraded with improved mooring, berthing and offloading facilities to assist in the expansion of this potential new industry. The mussel industry has improved its fleet in recent times in anticipation of the release of these new aquaculture areas. With the closure of the wild scallop fishery in Port Phillip Bay and the limited catches from the coastal fishery there is a significant demand for scallops by processors with excess capacity as well as under-supplied markets.

Access to venture capital is always difficult, particularly for development of an industry with a lead-in time of three years before profits could be expected. There are, however, a number of individuals and companies that have shown significant interest in the development of scallop aquaculture in Port Phillip Bay.

A concern often sited is that should the wild scallop fishery recover it could affect market price and, ultimately, make the aquaculture of scallops unprofitable. This is unlikely to occur, given the experience around the world. Aquaculture scallops have some significant advantages over wild-caught scallops from a marketing perspective, including:

- reliable supply with predictable short term delivery
- high quality meats
- value-added products (live, shucked and half shell)
- year-round supply
- ability to withhold from market when price is low.

These attributes are key market advantages, which make scallop aquaculture very popular with both wholesalers and retailers.

Development scenarios

There are many ways in which any scallop culture industry can develop. The scenarios below show two of the most likely directions that a developing industry would follow.

Low-risk development

The first scenario would be an individual or small private company acquiring a licence area within one of the new aquaculture zones that should be suitable for scallop culture. Development of the farm would be based predominantly on mussel culture, which is currently profitable. The operator would attempt to catch scallop spat and, if successful, would begin to trial small-scale commercial production. Over the next few years the operator would expand into more scallop culture as finances and experience increases.

Advantages:

- Low financial risk;
- Allows time for developing expertise;
- Able to produce other product should scallop spat fall not occur;
- Enable staged development of markets (local, state and national).

Disadvantage:

- Larger competitors may acquire more area and control key markets;
- Larger competitors may reduce market price to make small operators financially non-viable;
- Low economies of scale may not allow product to be produced at low enough cost for consumers;
- Risk of high losses from equipment failure due to limited number of longlines.

High-risk development

The second scenario would consist of a company with substantial capital that would acquire one or more aquaculture farming areas (20 ha) suitable for scallop culture. This operation would set up all the farms for full production within the first year. Development of expertise would be through acquisition of experienced staff and ongoing research and training. Staffing levels would be initially higher to cover unforseen bottlenecks. The company would develop processing capabilities in conjunction with a marketing section. All sections would be working toward maximum profitability within one company. This group would also be looking at the long-term strategy of hatchery production to underpin reliable production.

Advantages:

- Potential acquisition of a number of sites at low cost due to initially low perceived value on market;
- Ability to input high technical skills for spat collection and a larval monitoring regime resulting in improved reliability of spat supply;
- Economies of scale for purchases of equipment;
- Larger operation increases the development rate or expertise;
- Ability to acquire equipment such as boats, washers, graders, floats etc. specifically for scallop culture;
- Larger producer allows for year-round supply;

- Large enough to make a value adding, processing and marketing operation viable;
- More likely to be a major player and drive the industry's development;
- Potential for substantial return on investment.

Disadvantages:

- The need to make strategic decisions without sufficient knowledge of sites and scallop culture;
- Lack of scallop spat supply would lead to financial hardship;
- High overheads and interest payments on venture capital;
- The need for rapid success and profits due to size of investment;
- Difficulty in accessing sufficient experienced staff;
- Large financial risk.

The development scenarios would need to include a number of areas that require a strategic framework; these areas include government, research and development, extension, commercial development, production schedules and marketing. Possible time lines linking these areas are found in Table 7.3.

Table 7.3 Possible time lines for alternative hanging cage culture development in Victoria. These time-lines are estimates based on past development occurring in Australia and around the world. A range of factors including political, social, financial, environmental and biological constraints will drive the actual development times.

Year	Organisational frame work by government	Research Development & Extension (MAFRI)	Commercial development		Production schedules
Y 1		Scallop growth & conditioning trials. Extension.			
Y 2		Scallop growth, conditioning and spat collection trials. Extension.			
Y 3	1. Acceptance of ECC recommendations 2. Development of management plans for zones.	Scallop growth, conditioning and spat collection trials. Extension	Development of new commercial aquaculture zones through staged approach.		
Y 4	1. Call for tenders form potential shellfish farmers 2. Allocation of licences. 3. Environmental monitoring	Scallop growth, conditioning and spat collection trials. Extension	LOW RISK Farm construction for mussels and scallop spat collection	HIGH RISK Construction of multiple farm sites	Catching of scallop spat
Y 5	Environmental monitoring of aquaculture zones	Spat collection and handling trials. Antifouling trials. Extension.		Construction of additional farms and processing capacity	First scallops to market, (mostly live scallops)
Y 6	Environmental monitoring of aquaculture zones	Antifouling, earhanging & enhancement trials. Extension.	Increase percentage of farm for scallops	Development of export markets	Product line expanded to: Live shucked half shell
Y 7	Environmental monitoring of aquaculture zones	Antifouling, earhanging & enhancement trials. Extension	Expand farm and concentrate predominantly on scallop culture	Continued development of farms and export markets.	
Y 8	Environmental monitoring of aquaculture zones				

Financial risks

Any new aquaculture venture is usually regarded as a high-risk proposition and any potential investor must review all areas that may pose a risk to the development of a successful operation. Many of these risks have been discussed in previous sections. The following list includes the areas that have potential to affect the financial viability.

1) Growout technology proves too labour intensive due to:
   - high fouling rates
   - low spat catches.
2) Higher than expected mortality due to:
   - predation
   - disease.
3) Lack of sufficient feed for scallops to achieve high quality.
4) Poor business and farm management due to lack of experience in aquaculture operations.
5) Theft and vandalism.
6) Increases in government taxes and fees.
7) Damage to farm by storms or shipping.

7.6 Business plan options for enhancement (re-seeding)

There are numerous options available for an enhancement operation conducted outside of Port Phillip Bay in Victoria. A number of these options have been discussed in Section 4.4 of this report. The options available for *P. fumatus* are even greater than *A. balloti*, due to the possibility of catching spat in the wild as well as spat production in a commercial hatchery. The potential for spat catching has been discussed in the hanging culture section and is generally applicable to the catching of spat in the open ocean. There are restrictions, however, in that spat collection in this environment is far more variable than in the confines of Port Phillip Bay (Coleman 1990, 1998). The use of spat collected in Port Phillip Bay has considerable risks associated with inadvertently transplanting exotic species that currently occur in the Bay.

We believe there is little likelihood for immediate success of an enhancement operation based on capture of wild *P. fumatus* spat from Bass Strait, and have therefore anticipated and modelled an operation based upon spat production from a hatchery. Such an operation requires considerable capital and expertise, and carries considerable risk, particularly in terms of uncertainty about natural mortality rates and growth rates of released spat. There are few available data or estimates for these parameters, and considerable circumstantial suggestion of inverse density-related mortality rates. Hatchery-based enhancement operations for scallops have had qualified success in France, but only because there has been massive and prolonged government support.

We can envisage two broad procedures under which a scallop enhancement project in Bass Strait could be developed and trialled. The first is a relatively low-risk option (as in Section 4.4), that involves the use of government hatchery facilities to improve and test hatchery procedures, undertake experimental research on re-seeding technology and investigate growth and mortality rates as functions of location and density. This might entail utilisation of the proposed new MAFRI hatchery for pilot production of spat and small scale re-seeding programs in areas known to produce scallops such as Lorne or Lakes Entrance. Major risks to such a process include the prolonged lead-in time and possible misleading results from re-seeding small areas, through failure to saturate predators.

The alternative would be to commit to a full-scale commercial hatchery at a fishing port such as Lakes Entrance and attempt a full-scale enhancement operation with a continuous internal monitoring program being a core element. Such a project would be capital-intensive and runs an appreciable risk of failure, being dependent upon unknown mortality rates.

Finding venture capital for such an option would be a major challenge unless government were to see the decline of the Bass Strait scallop fishery as being of such social significance as to justify investment of some millions of dollars before the project could hope to be self funding and return a dividend on investment. Developing a cost recovery procedure would in itself be a significant commitment of resources and debate.

Although these options require considerably more appraisal and review than we were able to commit to in this project, an approximate timetable would look similar to the one on the next page.

Year	Organisational framework	Process	R&D phase	Commercial hatchery development	
Y 1		FRDC feasibility study complete			
Y 2	• Government commitment • Exclusive access area concept signed off by Commonwealth	Operating plan and budget agreed to	Build and develop hatchery technology at MaFRI (Victoria)		
Y 3	Extension program, promote concept to industry	Operating company established – mostly private, some Govt. advisory role, but to be phased out	Ditto, studies on seeding survival as a function of handling techniques, size at release	LOW RISK	HIGH RISK Commence land purchase and infrastructure development
Y 4			Capacity to release 2–3 $*10^6$ spat on an experimental basis, in a 1 km^2 area, plan and conduct development plan		Hatchery developed and operating Release 5 * 10^6 spat into 2–3 km^2 re-seeding area
Y 5			Harvest, evaluate	Commence land purchase and infrastructure development	Release 20 * 10^6 spat into 6 km^2 re-seeding area
Y 6				Hatchery developed and operating	Release 25 * 10^6 spat into 9 km^2 re-seeding area
Y 7				Hatchery developed and operating Release 5 * 10^6 spat into 2–3 km^2 re-seeding area	Release 25 * 10^6 spat into 9 km^2 re-seeding area
Y 8				Release 20 * 10^6 spat into 6 km^2 re-seeding area	Harvest, release 25 * 10^6 spat into 9 km^2 re-seeding area
Y 9				Release 25 * 10^6 spat into 9 km^2 re-seeding area	Harvest, release 25 * 10^6 spat into 9 km^2 re-seeding area

8 Governance and development of *Pecten fumatus* culture and enhancement in Victorian and Bass Strait waters

8.1 Hanging cage culture

Individual operators, or private or public companies usually conduct hanging cage culture, with the cultured product being in the nature of a privately owned, rather than publicly owned, commodity. Authorisation to conduct hanging cage operations reflects the private enterprise nature of the operation.

The Victorian State Government requested that the Land Conservation Council (LCC) compile a report to select suitable areas for both marine national parks and marine aquaculture in 1991. In 1997 the Environment Conservation Council was formed replacing the LCC. Their final report, 'The Marine Coastal and Estuarine Investigation' was published in August 2000 (ECC 2000). The report's findings were based on an extensive consultation process over nine years that received over 5000 written submissions. Within this report are a number of areas recommended for aquaculture. Two of these areas, in particular, have potential as scallop culture sites as they possess the critical site requirements. These zones are both within Port Phillip Bay, which has historically been dredged for scallops. The two potential sites are:

- Pinnace Channel Aquaculture Zone (1000 ha)
- Mount Martha Aquaculture Zone (150 ha)

The ECC, Marine Coastal and Estuarine Investigation, Final Report was tabled in the Victorian State Parliament in September 2000. The report recommendations and its implications are to be reviewed and a decision regarding the acceptance or rejection of the report is expected in 2001.

The identification and allocation of new aquaculture and mariculture sites is a complex issue that has caused difficulties in all the Australian states as well as overseas in countries such as Canada and the United States. The Tasmania allocation system is based on a series of Marine Farming Development Plans (DPI & F 1995). These plans address:

- policy and legislative framework
- planning processes
- basis for zoning
- community consultation
- environmental impacts
- management controls.

In addressing these issues these plans have allowed for development that balances the requirements of both the public and private sectors. Any allocation of public water for commercial gain will be subject to extensive public scrutiny. In many cases, resolutions are difficult to achieve due to certain moral convictions that the marine environment should be left as pristine as possible. The acceptance of these moral judgments are usually the consequence of political processes that access and judge public views in conjunction with scientific advice, social needs, business pressures and environment implications.

The Victorian 1995 Fisheries Act requires management plans for each aquaculture zone to be implemented. Part of these plans requires monitoring to be carried out. Such monitoring should address concerns of chemical nutrient loading from scallop hanging culture. The extensive culture and the animal's ability to filter out substances make the use of chemicals impractical and undesirable from a human health perspective.

The Victorian Shellfish Quality Assurance Program would be able to encompass any new areas for shellfish culture under its current sampling regime. Any new area would increase the cost to the managers of the program, however, the farmers themselves are required as part of their licence conditions to contribute up to 30% of the total costs of the program. The ability to export from these new areas could be delayed from 1–2 years due to the requirement for background sampling to rate the area under the Clean Waters Policy contained within the VSQAP.

8.2 Marine ranching and enhancement

There is little likelihood of a marine ranching operation based on conventional harvest techniques being allowed to develop in Port Phillip Bay in the foreseeable future. There is, however, considerable interest in such an operation in waters off coastal Victoria, particularly near Lakes Entrance, and in Bass Strait, given the severely depressed state of the natural population.

Preliminary economic models suggest such an operation may be economically feasible, although there is considerable uncertainty about this, as natural mortality rates are effectively unknown. The process by which the operation would be regulated depends considerably on where and how it would develop.

An enhancement operation in Bass Strait would require authorisation under a range of Commonwealth legislation, including the Commonwealth Fisheries Act, and possibly, the Seabed Dumping Act as administered by Environment Australia's Marine Section (Environment Protection Group), and the Environmental Protection and Biodiversity Conservation Act. The issue of exclusive access areas would be triggered if the enhancement operation was operated for a subset, rather than all, endorsed fishers. We believe this could be managed under Commonwealth fisheries legislation, as an area closed to fishing and entry by licensed fishing vessels other than those entitled to harvest under the conditions and arrangements of the enhancement operation but warn that professional legal advice should be sought about such arrangements.

Should an enhancement operation be developed in State waters managed under Victorian legislation, the legislative protocol referred to above will control the operation. There may be a series of local authority requirements associated with the establishment of a hatchery, and State environmental authorities may have certain administrative responsibilities to do with hatchery water discharge standards.

There appears to be no critical barriers to the development of hanging cage culture or enhancement operations outside of these requirements.

9 Conclusions, acknowledgements

We have reviewed scallop enhancement and culture operations around the world, and found that scallop culture has been attempted in first and third world economies with very mixed success. There has been little consistency of operational conditions or economies for scallop culture operations that have succeeded. Successful operations could be associated with low labour costs, prolonged cultural and economic commitment to scallop culture, unique and favourable environmental conditions or casual disregard for long-term environmental impact. Unsuccessful operations, on the other hand, were often undercapitalised, lacked long-term commitment, or were based on species with very slow growth and prolonged lags between settlement and growth.

We have undertaken detailed appraisal of the economic and social constraints mitigating against the success of saucer scallop *(Amusium balloti)* culture, and a less detailed review of impediments to culture of commercial scallop, *Pecten fumatus*, in southern Australian waters. Within the constraints of knowledge gaps on natural mortality rates and hatchery technology, culture of *A. balloti* via marine ranching operations appears to have considerable prospects of being economically viable, and possibly highly profitable. The major constraints to the development of a successful saucer scallop enhancement operation appear to be data gaps, investment capital prepared to accept the 3–7 year lag between initial investment and subsequent return to capital, and constraints imposed by conservation interests.

Our appraisal of the feasibility of culturing *P. fumatus* was less comprehensive, partly because of the complexity and potential diversity of culture options, and partly through data limitations. Hanging cage culture seems to offer some capacity for profitable operations provided spat can be collected from open water using conventional spat-collecting techniques. The technology for such operations is well known, documented and trialled. The existence of dedicated aquaculture sites gives considerable support and surety for such operations.

Open water re-seeding seems to be a far less certain option, despite the development of models that indicate profitability. Natural mortality rates are highly uncertain, there is a long lead in time before a re-seeding operation could hope to achieve worthwhile profits, and the venture would require considerable capital investment if it were to go ahead in an area like Bass Strait. This could only succeed with appreciable government support.

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Appendix 1: Industry workshop – Developing scallop enhancement operations

Background

The Fisheries Research and Development Corporation supported an extensive study on the feasibility of culturing, ranching or enhancing scallop populations in Australia. The study concluded that a ranching operation based on re-seeding hatchery-reared saucer scallops (*Amusium balloti*) into discrete beds in Queensland and Western Australia could be highly profitable.

The feasibility study looked at organisational and business structures under which an enhancement operation could be conducted, and set out some hypothetical time lines under which an enhancement operation could be conducted.

It was clear, however, that a scallop enhancement operation would not be successful in the absence of one or more private enterprise operations that were committed to the development of a profitable business. Such enterprises would need to develop detailed operational plans, including budgets, time lines and procedures for implementing a business. While part of this process might require research, FRDC has been clear and consistent that it will not fund research associated with scallop enhancement until a clear end use and user for the work has been identified.

FRDC therefore supported a workshop designed to establish whether appropriate business structures for an enhancement or ranching operation existed or could be put in place. The workshop was designed to explore key issues and unknowns associated with scallop enhancement.

The workshop was conducted at Hervey Bay in the period December 5–7. About 30 participants were involved. They included:

- four representatives from the Queensland Seafood Processors Association, plus a consultant working with members from this organisation who are attempting to establish a ranching operation in Queensland;
- four members of the Queensland (trawl) catching sector;
- representatives from Queensland and Western Australia's fisheries management agencies and from Queensland's Environmental Protection Agency and State Development Department;
- scientists with considerable experience in shellfish hatchery technology;
- members of the Queensland DPI Fisheries and Aquaculture research agency
- two FRDC staff members;
- two representatives from the Western Australian scallop industry, one of whom is heavily committed to an ongoing scallop enhancement venture in the vicinity of Geraldton;
- the executive officer of the Challenger Scallop Enhancement Company, from New Zealand. This company is running a very successful scallop management and enhancement operation.
- a political adviser from the Federal Minister of Agriculture's office;
- the Hervey Bay City Council Mayor.

The meeting's participants collectively held a wide range of expertise, a good balance of private enterprise and government representation, and included local and federal political interests.

Objectives

The stated objectives of the workshop were to:

- facilitate an agreed implementation model for saucer scallop enhancement ventures in Queensland and Western Australia;
- discuss how this preferred implementation model would be developed, including identification of industry and government responsibilities, information needs and research priorities;
- develop an agreed schedule for timing of each development step that is consistent with the business plan;
- finalise the business plan to incorporate stakeholder comments and outcomes of the workshop.

In reality, wider issues were addressed. A private company in Western Australia has obtained government approval to conduct a scallop ranching operation and has invested considerable time and money to improve saucer scallop hatchery technology during the past four years. Research staff from Queensland were also undertaking work on scallop hatchery technology with some success. At the same time, there are significant gaps in some aspects of knowledge about saucer scallop biology research and enhancement technology, particularly in relation to hatchery techniques, age-specific mortality rates and spat transporting procedures. There was obvious scope to develop research partnerships within the framework of the workshop.

A workshop of this nature also facilitated the development of local or national business networks and structures, and allowed participants the opportunity of seeing the proposed operation within the wider political framework. Finally, the workshop was also designed to allow industry representatives the opportunity of assessing the potential impact of an enhancement operation on existing fisheries.

Process

The workshop was lead by a professional facilitator. Given the complexity of the subject matter, the varying levels of prior knowledge and the range of expectations from participants, conventional meeting procedures were discarded. The meeting followed an open space process, in which a series of short information presentations were delivered as an introduction. The presentations covered FRDC's position on enhancement, a global review on scallop enhancement, a review of progress on hatchery R & D to date and a quick revisit of the FRDC feasibility study. Workshop participants then identified issues that would need to be fleshed out, clarified or developed before a scallop enhancement operation could become a reality.

These issues (some 30–40 one line items) were then prioritised by the workshop and discussed by smaller subsets of the workshop, who participated in discussions on the line items on a voluntary basis.

The discussions from a further subset of these discussions were then fleshed out in more detail.

Issues

The issues raised have been grouped into matters pertaining to business structure and organisation, matters of government responsibilities (including environmental impact and management), site selection, research needs, impacts on existing markets and industry, collaboration and miscellaneous matters.

The issues raised are grouped below. The numbers in parentheses at the end of each line are the outcome of a 'voting' process in which workshop participants registered their assessment of each item's significance.

Business structure and organisation

- How will a viable operating company be established? (26)
- Setting realistic time frames and budgets for development programs – 3/5/10 years (14)
- A national or Queensland approach – where does W.A. fit in? (11)
- Entry to company / co-operative – who gets to play, who gets to decide? (7)
- How will industry assume the leadership role? (7)
- How can we capture all opinions on hatchery and spat development and agree on a best approach? (9)
- What is a realistic time frame to set up an enhancement operation? (3)
- Aquaculture? Enhancement? Ranching? What is our focus? (3)
- How do we ensure equitable benefits to all stakeholders? (1)
- Need to get community on side (1)
- The fishery isn't in trouble. Why do we need an enhancement program? (0)
- Who will own the project? Who will benefit from it? Who will manage it? (0)
- What upper limits on re-seeding and/or ranching – areas for re-seeding, numbers of seed, total enhancement production. Why? (0)
- Managing an enhancement are – policing, predation control and other disasters (0)
- Who will pay? (0)
- How will we maximise $$$ to government, industry and others? (0)

Matters of government responsibilities (including environmental impact and management)

- Government approvals – a necessary part of the process (13)
- Seabed rights (6)
- ESD and biodiversity – issues and community expectations (2)
- Can/will legislation keep pace and allow the initiative to progress? (1)
- Supplying spat – the role of government hatchery vs a private venture hatchery (0)
- More information on the effects on water quality from vast numbers of animals (0)
- Environment – genetic impacts, disease, ecological impact and bycatch (0)
- More information on the effects on water quality from vast numbers of animals (0)
- Environment – genetic impacts, disease, ecological impact and bycatch (0)

Site selection

- Site availability – where, process to attain (Qld vs. W.A.) (12)

Research needs

- Research issues – how much is needed? what are priorities? (20)
- What is known about transport of < 10 mm spat – How to maximise cost effectiveness of seeding – cost of producing given size seed – How many seed of given size to harvestable scallops (11)
- Is open seabed seeding an optimum immediately following settlement and what techniques are involved? (8)
- Hatchery – faster development of methods to commercial quantities (6)
- Who owns the technology (2)
- Genetic selection – are we going to create a super scallop? If so, what is impact on wild stocks? (1)
- Identification of knowledge gaps in scallop aquaculture/enhancement technology (1)
- What are the bottlenecks in hatchery production & nursery rearing? (0)
- How do we produce more spat? (0)
- Can new technology change business - age at release, increased survival (0)
- Mortality rate on spat of varying size (0)

Impacts on existing markets and industry

- Impact on existing industry (15)
- How would enhancement affect the market place? (1)
- How the aquaculture industry can be developed in this area to achieve competitive advantage (0)
- What value-adding opportunities can result from this project? (0)

Collaboration, miscellaneous

- Scallop aquaculture is now bigger than wild scallop fisheries (1)
- How will all stakeholders be involved – industry, government, EPA, NGOs, researchers (0)
- W.A. & Qld – a co-operative approach or space race (0)
- Long term plan – do we want Hervey Bay to look like a bay in China? (0)
- Definitions and semantics

Review of issues discussion

Item 1: Impact on existing industry

Attending: Syd McKeon, Bill Hennebery, Hamish Ch'ng, Peter Loveday, Tina Thorne, Nick Shulz, Kylie Paulsen,

Comments:

Sectors affected

- Catching sector
- Marketing & processing sectors

Areas affected

- Positives – reduce import substitution, increase employment, guaranteed income, ecologically sustainable operation
- Market price & return to fishermen – the more produced the lower the price
- Ability to harvest stock (trawling) may be compromised in the future – are there alternative harvest methods?
- Access to enhancement areas should be open to steam over
- Equity between those involved and those not

National issues

- Potential cooperation between states given different fisheries management regimes plus number of fishermen plus number of boats
- National company may not be possible

Item 2: Government approvals – a necessary part of the process (Queensland focus)

Attending: Jim Gillespie, Alison Penfold, Mark Gough, Mike Dredge, Peter Dundas-Smith

Comments

Approvals process

- Hatchery needs aquaculture permit but no broodstock collection permit
- Is the act of putting spat in an area aquaculture? Definition of aquaculture is "culture of organisms/animals for sale"
- Use of aquaculture licence gives far more security under Queensland legislation

Environmental management issues

- If operation is in Marine Park some issues to do with biodiversity need to be addressed in a pilot project (what are terms of reference?). Approval for 12 months then 6 years.
- No changes to Regulations under Qld EP Act if operation is in Hervey Bay. Marine Park - authorisation by CEO approval. No EPA approvals if outside Marine Parks at this time.
- Hatchery – discharge/intake approvals.
- Whales an issue? – Probably not – no furniture so OK.
- EIS only if Fisheries Act comes under IPA – or if Chief Executive of EPA requires it (within Marine Park).
- Could this go to State Development as State Government priority program, with DSD as Project Manager?
- Native Title Notification and Native Title procedures – how do they apply?
- If in Marine Park EPA wants a reasonable assurance of transparency, measurement of environmental impact
- Broodstock management process – diversity to be maintained
- How to get certainty – if you are about to invest $2m – How to ensure environmental management demands don't gazump the process
- Does this trigger Commonwealth legislation – Possibly EPBC
- This process of environmental approvals is a key limiting factor

- The proposed operation has to define where & how it wants to progress – site, area
- No need for sea bed lease – approvals under Fisheries Act
- Resource access is the key to industry investment
- Fisheries management – how to close an area for a ranching operation. Easiest in an area where there is not much transit by the existing trawler fleet.
- Would there be a crown cost – resource rental or royalties?

Item 3: If the fishery is not in trouble – why do we need an enhancement program?

Attending: Ted Whittingham, Nick Schulz, Warwick Sheldon, Barry Murphy, Peter Perry

Comment

- Extent of market
- Price stability
- Cost efficiency
- Carbon efficiency
- Protection of industry

Item 4: Is open water seeding an option immediately following settlement phase and what techniques are involved?

Attending: Peter Duncan, Nick Duyst, Mike Heasman, Peter McGowan

Comments

- Open seedbed seeding immediately following settlement is an option
- The critical test is survival rates versus costs. Very large volumes @ low cost spat against size-specific survival projections
- WA hatcheries are trialling 0.25 through to 2 mm
- Survival rates have varied considerably area to area. Areas are surveyed for existence of predators prior to seeding
- An option is to grow to settlement size, relocate to open sea nurseries under predator mesh, then relocate to growing site
- Paspally successfully seeded immediately after settlement
- Trials with abalone have generated a lot of data which may be relevant
- Setting up a trial in Hervey Bay is a must. Some ideas on how this should be done need to be laid out

Item 5: Identification of knowledge gaps in scallops aqauculture/enhancement technology

Attending: Paul Grieve, Wayne Knibb

Comments

- Minimum age at release may change B:C ratio by orders of magnitude
- Increase % survival by selection among families = concerns for wild population or of benefit to wild population?
- Need pilot aquaculture and restocking to test TOA
- Capacity of extensive scallop restocking and/or aquaculture to remediate bays

Item 6: Entry to company/cooperative

- Who gets to play
- Who gets to decide
- How will industry assume a leadership role?

Attending: Peter Loveday, Sid McKeown, Warwick Sheldon, Peter Dundas-Smith, Kylie Paulsen, Barry Murphy, Bill Hennebery, Peter Perry, Darren Flaherty, Ted Whittingham

Comments

- Industry needs to drive the agenda
- Advertise group is being formed and conduct an open meeting
- Denis Longhurst has been employed by a consultant – in Queensland to look at possibilities, research needs
- Inside or outside industry
- Scallop enhancement / zoning ? participants
- Need a spat source at a known price and regularity of supply
- Needs to be commercial
- Hatchery establishment should have NO UPFRONTGIVENS – critical establishment criteria include biological limitations, water quality, infrastructure, capacity to service, locations
- Capital $1–1.5m ($400 000 TO $500 000 operating per year)
- Rod Grove-Jones is hatchery expert who has established commercial hatchery for abalone. Someone needs to go to Port Lincoln & look at the hatchery & talk about scallop operations
- NZ $1.8m, 50 boats, 12 + quota, $17 kilo.
- Manage access
- Company to provide structure – vertically integrated
- Hatchery needs to be land-based – while barge/ship-based operation has appeal, sanitation and operating costs are significant limitations

Business plan

- Threat of takeover/concentration of ownership
- Entry limit % any one owner/co. can have
- Could sell rights to harvest
- Can't be open door
- Must be involved and independent

Item 7: Genetics

Attending: Tina Thorne, Mark Gough, Peter Duncan?, Hamish Ch'ng, Duncan Biggs

Comments:

- There is national translocation policy that WA has included with its enhancement operation licensing
- Problem with WA legislation does not allow differentiation of genetic stocks (only endemic versus non-endemic).
- WA has licence conditions for mollusc re-seeding e.g. sanitation, disease
- Carrying capacity needs to be defined in relation to water quality conditions
- Need to be able to identify stocked versus naturally settled scallops
- Are there different genetic strains of scallops? (Not in Queensland, but W.A. & Qld populations are different)
- Make sure broodstock comes from the area to be stocked

Predators

- What are they?
- Does an enhancement program attract predators?
- Starfish removal?
- In Jervis Bay experimental re-seeding, sting rays were problem
- Need for consultation with community interests up front
- Cumulative impacts/ total extent of activity
- Loggerhead turtles transmit a nematode parasite to scallops
- Water quality for hatching (marine, oceanic quality is needed)
- Site issues for hatchery

Item 8: Hatchery enhancement program and timing

- What are the bottlenecks?
- Where do we go from here?

Attending: Nik Duyst, Denis Longhurst, Wayne Knibb

Comments

- Hatchery technology sound until settlement stage
- Catch 22: Research agencies will not develop hatchery technology further until solid business plan exists and business will not develop business plan until technology is fully developed. Requires industry spokesman to focus
- Denis – group together to initiate project for trial enhancement. Perhaps now concentrate on spat "freshly" settled and continue trial up size gradient i.e. test growth & mortality of seed at set, at 0.5 mm, at 1 mm etc. – need pilot project asap
- Set up working group, very soon and get R&D Program
- Transport issues for moving spat from Bribie Island to Hervey Bay, and in Geraldton, to release site

Funding

- Who?
- Industry/FRDC/Government need to define, find funding sources
- Must recognise needs of private company as well as Bribie/Government wanting to hold Intellectual Property. Company requires some ownership of technology
- When working with pilot project, if private company putting in money for R&D, what is stopping other companies gaining IP (after developed) and competing

Conclusion: must get away from academic angle and start commercial production. Govt. can help but concentrate on practical angle

Item 9: Seabed rights

Attending: Cr Belinda McNevan, Kylie Paulsen, Peter Loveday, Nick Schulz, Peter McGowan, Ted Whittingham, Sid McKeown, Warwick Sheldon, Barry Murphy, Bill Hennebery, Peter Perry, Darren Flaherty

Site selection

- Local stock – determines level of stock on grounds
- Outside GBR World Heritage Area – western side of Hervey Bay

Rights

- No rights once scallops are on the ground
- Who has the right to harvest them – recreational, commercial, indigenous interest etc.
- Closure to an existing fishery – will there be compensation or social benefits for others i.e. displaced industry.

Licence conditions

- Environmental monitoring

Planning

- Need a clearly defined planning process

Legal issues

- Aquaculture licence over particular area with fishery closure
- Don't need seabed lease
- Can be run under fisheries legislation
- Needs clear legislation

Area

- $15nm^2$

What Needs To Be Done!

- Determine criteria for site selection – predation, water quality, temperature and flows etc.
- Establish social and political concerns and costs
- Need strong business decisions

Hatchery site selection criteria

- Need to establish criteria for site selection
- Are site criteria developed by WA relevant to other areas
- Transport times and impact on mortality
- Life stage at which to transport
- Technology required for effective transport – mesh, bags, circulation systems, water conditions quality and temperatures etc.
- Need wide base of experience

Enhancement site selection criteria

- Need to establish criteria for site selection
- Proximity to hatchery
- Known capacity to support scallops
- Impact on other users – impact on major fishing grounds
- Environmental sensitivity – dugong protection areas, whales, turtles, existing benthic communities
- Predator free zones
- Water quality – temperature, water flows (currents, tides etc.), proximity to flooding areas/rivers
- Depth and visibility – ability to dive on the site to evaluate impact etc. (needs to be less than 20 m)
- Obtain existing criteria developed by WA
- Transport times and impact on mortality
- Life stage at which to deploy
- Need wide base of experience to draw from

Development of business plans – time lines, R&D, budget – for illustrative purposes

Year	Date	Commercial venture	Pilot and research operations	Cost $$
2001	5–7 Dec	Scallop enhancement workshop		
	Dec	Impact assessment on existing industry		
	Dec	Identification of beneficiaries		
	15 Dec	Meeting of all foundation stakeholders to discuss company/other structure Peter McGowan & Co. distribute spat in WA fishery		
	Dec		Meeting with DPI and UQ to discuss critical path for first phase research and development – – identify and prioritise issues, – determine size for spat into ocean determined, best approach – identify potential costs associated with venture – capture understanding and knowledge that currently exists. Develop action plan – Role of BIARC identified, resolution of intellectual property ownership issues e.g. spat production	
2002	Jan	Expression of interest for enhancement in hatchery (under the "Invest Wide-Bay" Initiative)		
	Feb	Communication plan developed – identify stakeholders – commence informing stakeholders of activity		
	Feb		Identification of budget and funding streams for initial development, agree to draft R & D issue identification and risk assessment	
	Feb 14	Distribution of proposal document (business plan) for comment/endorsement.		

Year	Date	Commercial venture	Pilot and research operations	Cost $$
	Feb	Agreement on business plan		
	Feb	Identification of operational budget for long term operations (infrastructure, staff etc.)		
	Feb	Follow-up from meeting with DPI review actions	Follow-up from meeting with DPI review actions	
	Feb/ March	Formation meeting		
	Feb/ March	Establishment of company		
	Mar	Agreement of site selection criteria (short, medium and long term; large potential area with defined smaller sites)		
	Mar/ Apr	Identification of potential sites		
	Mar/ Apr	Pre-lodgement discussions with approval authorities commence		
	Apr	Review disease control procedures/plan		
	Apr/ May	Application/submission for site and relevant permits and authorities		
	Apr/ May	Environmental monitoring program developed by managers and community		
	Apr/ May	Broodstock submission		
	May	FRDC funding announced		
	May	R&D priorities established	R&D priorities established	
	Jun	Feasibility of aquaculture hatchery, including site selection criteria		
	Jun	R&D projects for 2003 FRDC funding round developed		
	Jul	Announcement of second round of "Wide-Bay Invest" initiative		
	Jul		Transport trials	20 000
	Jul/ Aug	Community consultation and education of the benefits and operation		

Year	Date	Commercial venture	Pilot and research operations	Cost $$
	Sep	Development of human capital (industry leaders, technologists etc.)		
	Sep		Evaluation of mortality and growth rates during trial	100 000
	Nov		Preliminary results of deployment	
	1 Dec	Applications to FRDC submitted		
2003	Apr/ May	Site approval		
	Apr/ May	Conduct research on site to determine baselines		
	Apr	Scallop Enhancement Company Ltd Meeting		
	Apr		Saucer scallop enhancement workshop to discuss preliminary results and deployment (Qld and WA)	
	Apr	Decision on commercial hatchery (5 hectares??)		
	Apr/ May	Enhancement hatchery approval		
	Apr/ May	Broodstock approval		
	May/ June	Environmental monitoring programagreed by managers and community		
	May/ Jun	Environmental impact monitoring and data gathering commences (ongoing)		
	Jul	National marketing strategy developed		
	Jul	National industry strategy developed	Pilot project operational (spat dispersed)	
		Age specific mortality and growth underway		
		Market sensitivity and volatility assessed		
		Full scale enhancement operation underway		
		ESD and performance criteria		
		Industry voluntary R&D levy		

Year	Date	Commercial venture	Pilot and research operations	Cost $$
	Apr	Outcome of first spat deployment assessed - Successful? Additional trials required?		400 000
2004	Feb	Commercial hatchery commences		
2006	Nov		Results of deployment known	
	Jun	Genetic (triploidy etc.) R&D commences		
2008		Scallop enhancement fishery co-management (Company responsible for management of enhanced scallop fishery)		
2010		Value of scallops $300m		

Purpose

In the short – medium term

1) To develop sufficient information upon which to make serious investment decisions about scallop enhancement

2) To enhance industry and make money, increase opportunities for regional employment and generation of income

3) To develop and support discreet scallop ranching operations in Queensland and Western Australia

In the longer term

1) To develop a major and diverse industry based on supply of premium quality saucer scallop products to a wide array of markets.

Outcomes

The stated objectives of the workshop were to:

- facilitate an agreed implementation model for saucer scallop enhancement ventures in Queensland and Western Australia;
- discuss how this preferred implementation model would be developed, including identification of industry and government responsibilities, information needs and research priorities;
- develop an agreed schedule for timing of each development step that is consistent with the business plan;
- finalise the business plan to incorporate stakeholder comments and outcomes of the workshop.

It is premature to identify if these objectives have been translated into meaningful outcomes at this time, however:

- A scallop ranching venture has approvals and is in its third – fourth year of an R & D phase in Western Australia at this time. Some of the issues addressed by the Western Australian company were discussed at the workshop, and, hopefully, Queensland participants were able to get a realistic idea of the time frames, costs and expertise required for a hatchery-based ranching operation
- The Western Australian government has developed procedures for authorising a scallop ranching operation and Queensland government participants have put the framework of an approval process for enhancement or scallop ranching together.
- Workshop participants generally agreed that a sea ranching operation in a selected but limited area, using hatchery-reared spat, was a good way to develop a viable scallop enhancement industry that might lead on to a more substantial operation.
- A Queensland based consortium has agreed to establish a company with objectives based on the idea of undertaking R&D, and commercialising, saucer scallop ranching operations. They have employed a consultant to develop the outlines of a business plan and initiate the process of approvals.
- Government support and funding opportunities for a re-seeding operation were identified.
- Site selection procedures, incorporating decision rules for both hatcheries and ranching sites, were initiated.
- An initial attempt to develop a business outline – time lines for specific activities, budgets and pilot scale operations – was commenced.

Issues that were not developed as successfully during the workshop included:

- Key information gaps on saucer scallop biology as related to sea ranching were identified but not fleshed out in detail.
- Development of research priorities, a research risk assessment (i.e. how much knowledge is needed vs how much time and cost ventures are prepared to risk) and a national approach to research. Given the time frame and relatively early stage of the operation in Queensland, this was not surprising, but is an issue that should be followed up.
- Discussion of hatchery protocols and requirements was limited, as was discussion on hatchery engineering and site location.
- The development of a national approach to saucer scallop ranching was not explored in any detail.

There is obvious scope to keep working on these issues after the workshop, given the networks that have been established as a consequence of the workshop.

The future

Saucer scallop ranching and, possibly, enhancement could become a test bed for enhancement operations in Australia. The species has rapid growth, is sedentary after settlement, has high meat value and demands considerable labour for its production and processing. It is unusual amongst shellfish, in that it has never been recorded as transmitting any form of dinoflagellate-based toxin poisoning. Early indications are that the species will not require extensive work for hatchery-reared spat to be identified. The species therefore lends itself to culture on the basis of economic, social and environmental justification. If enhancement operations do proceed, there is a good case for research agencies and fisheries and environmental management bodies to advise, support and monitor the operation on a national basis.

For saucer scallop culture to become a reality there will be a need for long term commitment by private enterprise, research providers and funding agencies. Environmental management agencies, the existing catching sector and the public at large will need to be aware of proposed ranching and culture operations.

At the same time, a large scale ranching or re-seeding operation may have unpredictable effects on existing markets. Some members of the catching sector may find a ranching operation a threat, both in terms of marketing issues and the alienation of potential trawl ground. Despite these issues, allowing the present fishing operations and management structure to remain where they are will condemn the existing fishery to become a sideshow and face the risk of becoming irrelevant if and when other scallop and bivalve enhancement operations come on line in Australia and other countries.

Participants

Mr. Robin Hansen
36 Old Scenic Road
YEPPOON Q 4703
Queensland
TEL: (07) 4933 7395 FAX: (07) 4933 7395
E-MAIL: rear@cqnet.com.au

Mr. Darren Flaherty
20, Riverview Drive
CALLIOPE 4680
Queensland
ddflaherty@bigpond.com

Mr. Peter Loveday
227 McCarthy St
BUNDABERG 4670
Queensland

Mr. Sid McKeown
FISHMAC
15e Quay St.,
BUNDABERG 4670
Queensland
Fishmac@ozemail.com.au

Mr. Ted Whittingham
Hervey Bay Seafoods
P.O. Box 1470
GLADSTONE 4680
Queensland
hbfprocessor1@bigpond.com.au

Mr. Vern Lee
Lee Fisheries
P.O. Box 54
TINCAN BAY 4580
Queensland

Mr. Nick Shultz
C/ Urangan Fisheries
Lot 1, Boat Harbour Drive
HERVEY BAY 4655
Queensland

Mr. Denis Longhurst
Management Strategies
21 Swan Drive
HERVEY BAY 4655
Queensland
Email: denislonghurst@bigpond.com

Mr. Duncan Souter
Q.S.I.A.
P.O. Box 392
CLAYFIELD 4011
Queensland

Mr. Hamish Ch'ng
Farwest Fisheries
31, Emplacement Cres
HAMILTON HILL 6163
W.A.
Email: farwest@bigpond.com.au

Mr. C. McGowan
Cape Inscription Pearls
P.O. Box 2144
GERALDTON 6531,
W.A.

Mr. Mike Heasman
NSW Fisheries
Port Stephens Research Centre
TAYLORS BEACH 2316
N.S.W.
Email heasmanm@fisheries.nsw.gov.au

Mr. Peter Dundas Smith
FRDC
P.O. Box 222
DEAKIN WEST 2600
A.C.T.
Email: peter.dundas-smith@frdc.com.au

Ms. Kylie Paulsen
FRDC
P.O. Box 222
DEAKIN WEST 2600
A.C.T.
Email: kylie.paulsen@frdc.com.au

Mr. Jim Gillespie
Queensland Fisheries Service
Q.D.P.I.
P.O. Box 46
BRISBANE 4000
Queensland
Email: Jim.Gillespie@dpi.qld.gov.au

Mr. Paul Grieve
A.F.F.S.
P.O. Box 2066
WOORIM 4507
Queensland
Email: Paul.Grieve@dpi.qld.gov.au

Mr. Bob Pearson
A.F.F.S. Q.D.P.I.
P.O. Box 46
Brisbane 4001
Email: Bob.Pearson@dpi.qld.gov.au

Dr. Wayne Knibb
A.F.F.S.
P.O. Box 2066
WOORIM 4507
Queensland
Email: knibbw@dpi.qld.gov.au

Dr. Peter Duncan
Lecturer (Aquatic Ecology)
Faculty of Science
The University of the Sunshine Coast
MAROOCHYDORE DC 4558
Queensland
Email: pduncan@usc.edu.au

Mr. Mark Gough
Environmental Protection Agency
160, Anne St.
P.O. Box 155
BRISBANE ALBERT ST 4002
Queensland

Mr. Andrew McNamara M.L.A.
P.O. Box 953
HERVEY BAY 4655
Queensland

The Hon. Mr. Warren Truss M.H.R.
319 Kent St.,
MARYBOROUGH 4650
Queensland

Mr. Bob Hockey
Acting Director, State Development Centre
P.O. Box 537
MARYBOROUGH 4650
Queensland
Email: bob.hockey@sd.qld.gov.au

Mr. Peter Perry
P.O. Box 6104
BUNDABERG 4670
Queensland

Mr. Ted Sorensen
Mayor, Hervey Bay City Council
(Attn Ms. Lorraine Rolfe)
P.O. Box 5045
HERVEY BAY 4655
Queensland

Bill Henebery
16 Honeysuckle Drive
BOKARINA BEACH 4575
Queensland
Email: henebery@austarnet.com.au

Mr. Russell Mincher
Challenger Scallop Enhancement Co
P.O. Box 175
NELSON
New Zealand
Mincher@scallop.co.nz

Mr. Barry Murphy
17 Mahogony St.,
SCARNESS 4655
Email: BarryJohnMurphy@bigpond.com

Mr. Nik Duyst
22, Foxwood Court
Dundowran
HERVEY BAY 4655
Email: Nduyst@bigpond.com

Ms Alison Penfold
Advisor,
The Hon Mr. Warren Truss MP
Parliament House
CANBERRA 2600
A.C.T.
Email:Alison.penfold@affa.gov.au

Ms Tina Thorne
Fisheries Western Australia
3rd Floor, SGIO Attrium
168 St George's Tce
Perth 6000
W.A.
Email: tthorne@fish.wa.gov.au

Mr. Warick Sheldon
P.O. Box 1216
Gladstone 4680
BATTLESTAR@bigpond.com

Mr. Mike Dredge
Q.D.P.I.
P.O. Box 46
Brisbane 4001
Email: Mike.Dredge@dpi.qld.gov.au

Appendix 5

SCALLOP FISHERIES, MARICULTURE AND ENHANCEMENT IN AUSTRALIA

Mike Dredge

Queensland Fisheries Service, Southern Fisheries Centre,
P.O. Box 76, Deception Bay, Queensland 4508, Australia

1. INTRODUCTION

At least 50 species of scallop have been described from Australian coastal waters (Lamprell and Whitehead 1992), although the taxonomy of many is confused and contradictory. There are, however, appreciable fisheries directed towards only two of these species. These are a trawl fishery for saucer scallops, *Amusium balloti*, in tropical and sub-tropical waters off Queensland and Western Australia, and a dredge fishery for commercial scallops, *Pecten fumatus*, in temperate waters off Victoria, Tasmania and, rarely, off New South Wales.

Pecten fumatus was originally described as three species - (*Notavola alba* (Tate) in Victorian waters, *N. meridionalis* (Tate) off Tasmania, and *N. fumatus* (Reeve) off New South Wales, but Woodburn (1990) grouped these taxa into a single species on the basis of electrophoretic data. A separate species, *Pecten modestus*, occurs along the southern and south-western coasts of Western Australian. *Amusium balloti* was classified as *A. japonicum balloti* in its Queensland distribution, but the Western Australian distribution of the species was not recognised or referred to by Habe (1963). Until the taxonomy of the species is further investigated, the species will be referred to as *A. balloti* throughout its Australian distribution.

Queen scallops, *(Equichlamys bifrons)* and doughboys *(Mimichlamys asperrimus*) are taken as a byproduct or minor component of southern Australian fisheries. *Pecten modestus*, the Western Australian equivalent of the commercial scallop, has supported intermittent commercial fishing operations off the south-west Western Australia coastline and the mud scallop *Amusium pleuronectes* is sometimes taken in small quantities by Queensland and Northern Australian trawlers. There are minor commercial and recreational dive fisheries for *P. fumatus* and *P. modestus* in South Australia, Victoria and Western Australia, Dive and dredge fishing are permitted in Tasmania's recreational scallop fishery (Anon. 2000).

Australia's scallop fisheries have produced an average of 3,000 tonnes of meat, with a landed value of approximately Au$60m annually, which represents about 4% of Australia's total commercial fisheries production value (Caton and McLoughlin 2000).

Managers and resource users of all Australian fisheries, including those for scallops, have become increasingly aware of sustainability issues and the environmental impacts of fisheries. This awareness is partly attributable to legislative requirements. Most Australian fisheries statutes require fisheries to conform to the principals of ecologically sustainable development. Changes to the Australian Commonwealth *Wildlife Protection (Regulation of Imports and Exports) Act 1982* that will effectively prohibit export of products from fisheries that cannot demonstrate target species sustainability, ecological sustainability and negligible impact on endangered and threatened species, are creating substantial changes in the way that Australian fisheries are currently being assessed and managed.

This review will describe the biology, fisheries, management and mariculture potential of *P. fumatus* and *A. balloti*, and the social environment in which the fisheries exist.

2. HISTORY OF THE FISHERIES

The Australian scallop fishery for *P. fumatus* commenced in Tasmania's Derwent River estuary and D'Entrecastaux Channel (Fig 1) in the early to mid 1910s and peaked in the latter area in 1962, when production was in the order of 550 tonnes of meat (Table 1, Figure 2). During the fishery's early development, an unrecorded but appreciable proportion of the catch consisted of doughboy scallop (*Mimichlamys asperrimus* (Fairbridge 1953). The D'Entrecastaux Channel population collapsed in about 1965, and appears not to have recovered since then (Harrison 1965, Young and Martin 1989, Zacharin 1990a). Vessels moved from the Channel to scallop beds that were discovered along the eastern Tasmanian coast over a period of 10 - 15 years. There appears to have been a history of the coastal Tasmanian grounds being serially depleted and not recovering for extended periods, if at all (Young et al. 1990). The Tasmanian fleet first fished grounds in Bass Straits in the early 1970s, following successful survey work undertaken by staff from Tasmania's Department of Fisheries (Grant & Alexander 1973). Catches from the Bass Strait grounds have varied considerably since the fishery commenced, although catches in recent years have been taken from relatively small areas in the south-eastern areas of the Strait. Proportions of the Bass Strait catch landed in Victorian and Tasmanian ports can no longer be separated.

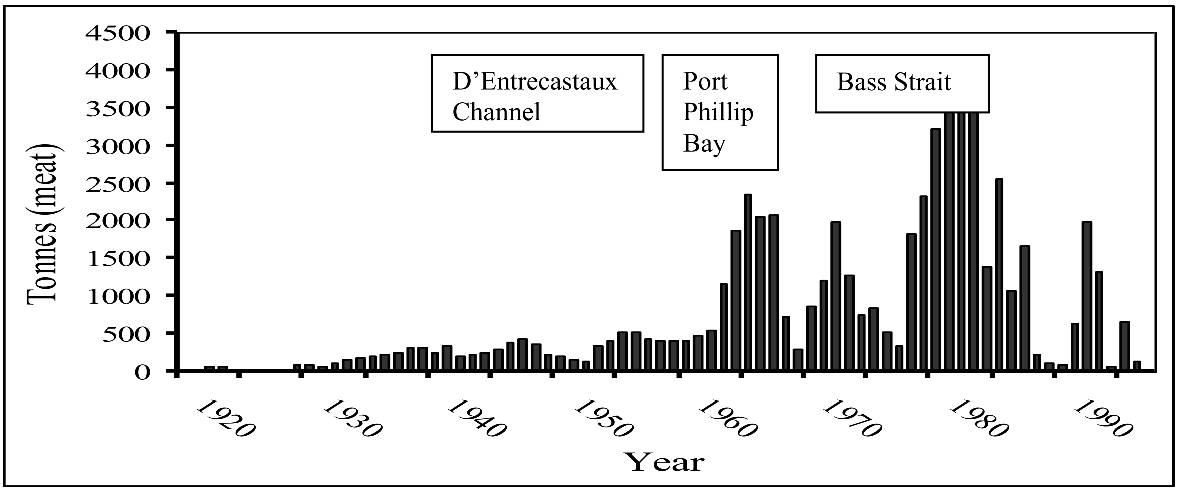

Figure 2. Annual production of *Pecten fumatus* in Australia

The combination of reduced Tasmanian catches, growing Australian markets and increased publicity about the existence of a scallop resource in Port Phillip Bay (Victoria) led to an explosive growth of fishing operations in this area. Upwards of 300 vessels, many from Tasmania, joined the fishery between 1963 and 1966 (Sanders 1970). Production exceeded 2,000 tonnes of meat in the peak production years of 1966 and 1967. The Port Phillip Bay scallop population declined in 1969 and much of the fleet moved to newly discovered beds off Lakes Entrance and other areas in Bass Strait. The Lakes Entrance and Bass Strait fisheries have persisted since that time, despite having to cope with irregular recruitment and intermittent closures caused by recruitment failure. The Port Phillip Bay fishery was closed in 1996, in response to community and political concerns about the impact of the fishery on benthic habitat and recreational fisheries resources (McCormack and McLoughlin 1999).

Table 1. Production of *P. fumatus* and *P. modestus* in Australian waters (meat weight, tonnes)

Year	*P. fumatus* Tasmania (a)	*P. fumatus* Total
1922	60	60
1923	75	75
1924	N/A	N/A
1925	N/A	N/A
1926	N/A	N/A
1927	N/A	N/A
1928	N/A	N/A
1929	80	80
1930	100	100
1931	75	75
1932	115	115
1933	155	155
1934	180	180
1935	210	210
1936	235	235
1937	260	260
1938	330	330
1939	315	315
1940	255	255
1941	340	340
1942	205	205
1943	225	225
1944	260	260
1945	300	300
1946	390	390
1947	435	435
1948	375	375
1949	235	235
1950	205	205
1951	165	165
1952	145	145
1953	335	335
1954	405	405
1955	520	520
1956	535	535
1957	430	430
1958	415	415
1959	420	420
1960	415	415

Year	*P. fumatus* Tasmania (a)	*P. fumatus* Victoria (b)	*P. fumatus* New South Wales (c)	*P. fumatus* Total	*P. modestus* Western Australia (d)
1961	475			475	
1962	555			555	
1963	440	730		1170	
1964	385	1495		1880	
1965	410	1950		2360	
1966	50	2010		2060	
1967	35	2040		2075	
1968	20	710		730	
1969	10	280		290	5
1970	0	660	220	880	260
1971	10	1155	50	1215	5
1972	80	1885	20	1985	10
1973	180	1110	1	1290	5
1974	195	560		755	
1975	105	740		845	
1976	75	450		525	
1977	60	285		345	
1978	165	1670		1835	
1979	590	1735	15	2340	5
1980	520	2530	180	3230	
1981	1165	2540	435	4140	5
1982	1780	1815	105	3700	5
1983	1340	2290	20	3650	15
1984	355	1035		1390	10
1985	465	2100*		2565	80
1986	770	300*		1070	2
1987	75	1600*	2	1675	1
1988	Closed	220*	5	225	65
1989	Closed	100*	3	105	
1990	Closed	90		90	
1991	Closed	650		650	
1992	1	1980		1980	
1993	Closed	1335		1335	
1994	Closed	75		75	
1995	245	410		655	
1996	40	90		130	
1997	Closed	10		10	
1998	540				
1999	700				

Source: a) Fairbridge (1953), Australian Fisheries Newsletter (1962-1980), Harrison (1965), Anon (2000): b) Australian Fisheries Newsletter (1962-1980), Gwyther (1990), Anon (1999): c) Stewart et al. (1991): d) Stewart et al. (1991)

* Data may be incomplete

The trawl fishery for *A. balloti* commenced in the mid 1950s off the central Queensland coast, between 23°S and 25°S (Ruello 1971), and in the early 1960s in Shark Bay (25°S – 26°S), off the Western Australian coast (Harris et al. 1999) (Fig. 1). Both began as secondary operations to existing prawn fisheries but have since become substantial fisheries in their own right. The fisheries benefited and expanded when meat quality was recognised on international markets. The bulk of the Australian *A. balloti* catch is now exported to markets in south-east Asia. A number of the trawlers that fish for *A. balloti* in Shark Bay also work in the vicinity of the Abrolhos Islands (28°S), and, occasionally, in waters south and west of Perth (32°S - 34°S), where recruitment is far less consistent than in Shark Bay. While more than 90% of average annual landings from the Queensland fishery have been taken between 23°S and 25°S, grounds in the vicinity of Hydrographer's Passage (22°S) receive intermittent recruitment and occasionally produce substantial quantities of saucer scallops (Figure 1).

3. BIOLOGY OF TARGET SPECIES

3.1 *Pecten fumatus*

3.1.1 Distribution and life cycle

Pecten fumatus has been recorded along the southern and eastern Australian coastline between western South Australia (133°E) and central New South Wales (30°S) (Woodburn 1990). *Pecten modestus* occurs in waters off southern and south western Western Australian, and a form of *Pecten*, described as *Pecten jacobaeus byronensis* (perhaps in error) by Fleming (1955), recruits intermittently in waters off southern Queensland and northern New South Wales.

Pecten fumatus is a functional hermaphrodite that normally spawns in winter and spring (June to November) in Tasmanian and Victorian waters (Harrison 1961, Sause et al. 1987a, Young et al. 1999), and in late winter and early spring towards the northern limits of its distribution (Jacobs 1983). The species normally attains sexual maturity in its second year. Under hatchery conditions the species has a 10-12 day larval phase (Dix and Sjardin 1975). There have been a number of studies directed towards understanding the timing of larval settlement in the species' natural environment, particularly in the context of predicting recruitment levels (Hortle and Cropp 1987, Sause et al. 1987b, Coleman 1990, Young et al. 1992). These studies have shown that maximum larval settlement onto spat collectors typically occurs in spring and early summer.

Hortle and Cropp (1987) and Sause et al. (1987b) recorded spat growth of 6 – 10 mm $month^{-1}$. Growth rates of juveniles and adults have been described by Fairbridge (1953), Sanders (1970), and Dix (1981), using tagging, shell check interpretation and size frequency analysis. These studies indicate that there is considerable variation in growth rates, with an average size of 30-40 mm shell length (maximum diameter) being attained in the first year, but in some circumstances attaining 60 mm in a year (Sause et al. 1987b). *Pecten fumatus* typically attains 70-80 mm in the second year of life and has an average maximum shell length (von Bertalanffy's L_∞) of 86 – 93 mm. There is some evidence of a change in the species' growth rates in its Port Phillip Bay distribution (Gwyther and McShane 1988), with growth rates increasing appreciably in a 20-year period. Whilst populations of *P. fumatus* including up to 16 year classes were recorded in the fishery's early history (Fairbridge 1953), the fishery is now almost entirely dependent upon 2+ and 3+ year old animals (McLoughlin 1994), which has caused concern about the potential for recruitment overfishing.

3.1.2. Mortality

While there have been a number of studies on predators and parasites that might cause mortalities to *P. fumatus*, there appears to be only one detailed study of population natural mortality rates for the species. Gwyther and McShane (1988) reported an annual instantaneous natural mortality rate (M) of 0.52, which is equivalent to an annual survival rate of approximately 60 %. Starfish (*Costinasterias calamaria)* and whelks (*Fasciola australasia*) were reportedly responsible for the death of as much as 80% of a scallop population in the D'Entrecastaux Channel, in southern Tasmania, over a four year period (Olsen 1955). A number of parasites, including mudworm (*Polydora websteri*) (Dix 1981), bucephalid trematodes (Sanders and Lester 1981) and nematodes (McShane and Lester 1984) have been reported to cause mortality of *P. fumatus* but the impact of these species on population levels have not been determined.

Population levels of *P. fumatus* in Port Phillip Bay were at historically near-low levels in 1999, despite the termination of the commercial fishery in 1996 (Coleman pers. com.). There is evidence that interactions between a number of introduced species, particularly the clam *Corbula gibba*, which is now very abundant in Port Phillip Bay, may be responsible for a decline in scallop abundance (Currie and Parry 1999, Talman and Keough, in press).

3.1.3. Monitoring, abundance and population dynamics

Population levels and population status of *P. fumatus* are monitored largely through fisheries statistics. Data on landings, effort distribution and catch rates for catches made in state waters are collected and collated by fisheries management agencies in Tasmania and Victoria, and by the Australian Fisheries Management Authority (AFMA), for catches made in the central, Commonwealth managed, zone of Bass Strait. Data are sourced from daily or monthly fisher returns. AFMA produces an annual assessment report (Caton and McLoughlin 2000) which includes a summary on the state of the Bass Strait scallop population, but the respective state authorities do not currently produce population models or assessment reports other than the production of fishery data as annual catch and effort summaries.

The Tasmanian Government authorises annual exploratory fishing operations by licensed scallop boats. Results from operations carried out by these boats are used to determine whether or not the fishery is opened in Tasmanian waters.

Although the Victorian State Government does not conduct stock assessments on scallops in Bass Strait, annual recruitment surveys and population assessments using diver observations were conducted in Port Phillip Bay in the period 1982 to 1996 (Coleman 1998), prior to the fishery's closure in this area. Survey data were used to estimate total population numbers and have served as catch predictors in the Port Phillip Bay area. The surveys demonstrated that recruitment variation within the Bay was considerable. High recruitment levels did not invariably lead to successful fishing seasons, as juvenile populations occasionally suffered high mortality levels. While the annual survey was discontinued in 1996, it has been repeated irregularly since then. The exceptionally low recruitment levels recorded in 1999, in the absence of commercial fishing, (Coleman pers. com.), may be a consequence of competition from exotic benthic organisms.

Sporic et al. (1997) attempted to relate commercial scallop recruitment and meat condition to environmental parameters, including nutrient and trace element levels, chlorophyll levels and coarser measures such as river flows, salinity and water temperatures. Whilst adductor condition of scallops could be related to some of the variables used in analysis (often on a time lagged basis), the only environmental variable correlated to catch rate was water temperature. The authors concluded that there was little scope for predicting scallop catches on the basis of environmental parameters. Recruitment and population levels in waters administered by the Victorian Government are now monitored through exploratory fishing operations. The results of these surveys are used to determine when and where fisheries for scallops are allowed.

Total catch data (Table 1, Figure 2), which are the only readily available, comprehensive and long-term information series on the population of *P. fumatus,* do not reflect the true state of the population. Rather, they reflect a complex series of fish-down events, some of which occurred over many years (as in the D'Entrecastaux Channel), discoveries of new beds, and irregular recruitment in areas such as Port Phillip Bay and the Bass Strait (Young et al. 1990). Caton and McLoughlin (2000) describe the species as being over-exploited. While detailed population models are not available, the general trends of effort distribution and total catch data support this conclusion.

3.2. *Amusium balloti*

3.2.1. Distribution and life cycle

Amusium balloti is a predominantly sub-tropical species that occurs in water depths of 15 – 50 m, typically between 18^0S and 25^0S along the Queensland continental shelf (Dredge 1988). Outliers have been recorded as far south as Jervis Bay (35°S), in New South Wales (Smith 1991). The species' Western Australian distribution extends between18°S and 35°S (Harris et al. 1999).

The species is gonochoristic and normally spawns in winter and spring (Dredge 1981, Joll and Caputi 1995a). It has a 12 –25 day larval phase under hatchery conditions, with settlement of post larvae occurring at a size of approximately 200µ. There is no evidence of more than a very transient byssal phase (Rose et al. 1988, Cropp 1994). This implies that conventional spat catching techniques are unlikely to collect *Amusium* spat. This observation is consistent with findings reported by Sumpton et al. (1990) and Robins-Troeger and Dredge (1993) in their studies on scallop spat collection in areas where *A. balloti* normally occurs. Successful settlement appears to create aggregations or beds of scallops. The only such beds that have been examined in detail were oblong in shape, with the longer axis lying parallel to the direction of tidal flow (Dredge 1985a).

Amusium balloti is characterised by exceptionally rapid growth. Joll (1988) has described the formation of daily growth rings in the Western Australian population of the species, and described growth rates of up to 2.2 mm week^{-1}. Williams and Dredge (1981) and Dredge (1985) reported von Bertalanffy parameters for k (instantaneous growth rate) in the range 0.052 – 0.059 week^{-1} and L_∞ in the range 101 – 108 mm, using both tagging and sequential size frequency composition data. These growth rate parameters imply the species can attain a shell height of 90 mm in 6 – 12 months. While maximum lifespan may be 3 years, the bulk of the fished population consists of 0+ and 1+ animals (Dredge 1994, Harris et al. 1999). The species is processed in roe-off form, and the adductor meat displays seasonal variation in condition, which has significant implications in terms of yield optimisation.

3.2.2. Mortality

Amusium balloti has the relatively high natural mortality rate consistent with a short-lived species. The only published report on natural mortality rates for *A. balloti* in its normal distribution estimated the instantaneous rate for M of 0.02 - 0.025 week^{-1} for scallops in the size range 50 – 110 mm (Dredge 1985b). This is equivalent to an annual mortality rate of approximately 60% for scallops in this size range. There are no data available on natural mortality rates of juvenile saucer scallops. Studies of predators and parasites that may be responsible for natural mortality are limited. Jones (1988) described the scyllarid lobster *Thenus orientalis* as a predator of *A. balloti*. Other known predators include octopus, a number of turtle species and the sparid *Pagrus auratus* (Harris et al. 1999). There have been no comprehensive studies on the parasitology of *A. balloti*, but the species is known to act as the intermediate host for an ascaroid nematode, *Sulcascaris sulcuta*, which uses loggerhead turtles, *Caretta caretta* as a final host (Berry and Cannon 1981). There are no data on the impact of this species on survival rates of *A. balloti*. The top shell *Capulus dilatata* parasitises A. *balloti* after boring into the shell, but its impact upon population levels is again unknown.

3.2.3. Monitoring, abundance and population dynamics

The major *A. balloti* resources of Western Australia and Queensland are monitored and assessed by means of annual recruitment surveys and review of commercial catch and effort data collected by fishers. Each state fisheries authority conducts a comprehensive annual survey to monitor recruitment levels and provide predictions of subsequent stock levels available to the fishery. Reviews of catch, effort and trends in both fisheries are published in annual or irregular fisheries status reports (Penn 2000, Williams in press)

Annual landings from the Western Australian fishery are strongly correlated with recruitment levels as estimated through the annual survey (Joll and Caputi 1995), and annual catch predictions are now offered on the basis of this survey (Penn 2000). The main determinant of recruitment levels in the Western Australian population appears to be prevailing environmental conditions driven by the el Nino – Southern Oscillation (ENSO) phenomenon. This, in turn, is thought to be related to the behaviour of the Leeuwin current system off the Western Australian coastline, although the exact mechanism driving recruitment levels remains unknown (Joll 1994, Caputi & Joll 1995). Recruitment and catch levels were an order of magnitude greater than the long term average in 1991 - 1993, years in which the ENSO event had major impacts on water movements and temperatures off the Western Australian coastline (Table 2, Figure 3). There appears to be no definable relationship between parent stock size and subsequent recruitment levels in the Western Australian population of *A. balloti*.

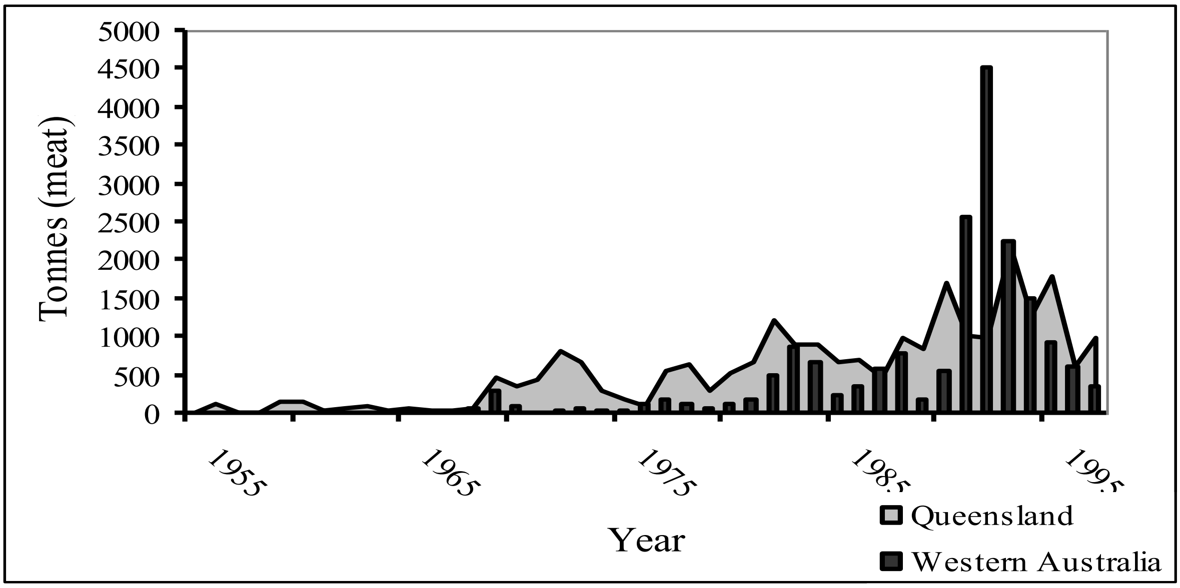

Figure 3. Annual production of *Amusium balloti* in Queensland and Western Australia

Table 2. Production of *A. balloti* in Australian waters (meat weight, tonnes)

Year	*A. balloti* Queensland	*A. balloti* Western Australia	Year	*A. balloti* Queensland	*A. balloti* Western Australia
1956	110		**1978**	645	109
1957	5		**1979**	280	57
1958	5		**1980**	520	113
1959	145		**1981**	660	169
1960	145		**1982**	1220	482
1961	35		**1983**	880	863
1962	60		**1984**	900	650
1963	75		**1985**	660	244
1964	40		**1986**	700	336
1965	65		**1987**	450	583
1966	40	1	**1988**	989	768
1967	30	N/A	**1989**	826	171
1968	55	69	**1990**	1689	557
1969	465	273	**1991**	1008	2567
1970	350	83	**1992**	983	4511
1971	430	NA	**1993**	2163	2233
1972	815	22	**1994**	1263	1488
1973	670	57	**1995**	1776	916
1974	300	36	**1996**	592	597
1975	180	33	**1997**	987	338
1976	100	111	**1998**	928	
1977	550	159	**1999**		

(Source – Queensland: Australian Fisheries 1956-1980, Stewart et al. 1991, Williams, in press, Western Australia: Harris et al.1999)

The Queensland fishery for *A. balloti* appears to exploit the resource far more heavily than is the case for the Western Australian population. There have been concerns about potential recruitment overfishing (Dredge 1988, Dichmont et al. 1999), which have lead to the introduction of precautionary management measures, including spatial closures to maintain spawner levels. Population assessments for the Queensland stock of *A. balloti* are now based upon reviews of commercial catch and effort data and information derived from an annual recruitment survey conducted in October each year (Dichmont et al. in press). The recruitment survey has been conducted for three years and is not yet capable of giving meaningful predictions of annual landings. Dichmont et al. (1999) have developed models to examine the status of the Queensland saucer scallop resource, but their value as a management tool or predictor for landings has not yet been tested.

4. FISHERIES AND THEIR MANAGEMENT

4.1 Pecten fumatus

4.1.1. Regulation

The major Australian fishery for *P. fumatus* is most readily described in terms of a single fishery managed by three jurisdictions. The Victorian Government is responsible for the species to a distance approximately 20 n. miles seaward of the Victorian shoreline. Tasmania has responsibility for management of scallop fisheries south of a line established under Australia's Offshore Constitutional Settlement that follows Latitude 40°45'S to about 144°E, and then approximately 20 n. miles seaward of the northern Tasmanian coastline. The Commonwealth of Australian is responsible for fishing operations in the area between the two jurisdictions (Figure 1). These arrangements can be linked to the fishery's history. The fisheries originated in coastal waters of Tasmania and Victoria, and moved to the oceanic waters of Bass Strait, the fisheries of which have historically been managed by a Commonwealth agency. Arrangements under which the three agencies co-manage the resource were formalised in 1986.

All three management agencies dealing with the major *P. fumatus* population in Victorian, Tasmanian and Bass Strait waters have had to deal with "boom and bust" fisheries that have attracted excess fishing capacity during boom years.

Managers administer the fishery in accordance with the objectives and requirements of three statutes, the Commonwealth Fisheries Management Act 1991, the Tasmanian Living Marine Resources Act 1995, and the Victorian Fisheries Act 1995. These statutes have some similarities in that they require sustainable use of fisheries resources amongst other objectives based on social and economic imperatives. All three jurisdictions have imposed limited entry into scallop fisheries, and many of the boats involved in the fishery have access rights to all three administrative zones.

While there has been no clear demonstration of a stock-recruitment relationship in the species, Young et al. 1990 presents limited data in support of the concept that spat settling in given areas of Bass Strait may originate from concentrations of spawners in the same areas. Depletion of spawners from such areas could therefore lead to localised recruitment failure. Managers in all three management areas support a policy of allowing scallops to spawn twice before being harvested, in order to minimise the risk of recruitment overfishing (McLoughlin 1994). In years of low recruitment, fisheries management agencies have closed the fisheries.

Tasmanian government policy on scallop resources now only allows for the harvesting scallops when there are adequate stock levels, at a time and size that will allow yield to be optimised (Anon. 2000). The fishery has been closed for 6 of the past 10 years in Tasmanian waters, due to low recruitment levels. Consequently, the fishery has become a secondary operation for the 117 vessels that currently hold licenses to fish for scallops. All vessels that are so licensed have access to other fisheries and fish for scallops irregularly.

The fishery operates on the basis of marketing a roe-on product, both to local and European markets, and is administered to maximise yield and value by allowing only winter – spring fishing, when gonads are at peak condition. Environmental impacts of the fishery are managed by prohibiting scallop dredging in sensitive shallow areas, by limiting dredge numbers and by requiring the use of dredges that minimise impact on the seabed.

The Victorian scallop fishery's management arrangements have been profoundly affected by the legislated closure of Port Phillip Bay to scallop dredging in 1996. The fishery was closed on the basis of social and ecological arguments, following jurisdictional procedures that had important implications for the nature of property rights in Australian fisheries (McCormack and McLoughlin 1999). The Victorian fishery is now restricted to coastal and oceanic waters to the south of the state, with an appreciable proportion of the state's landing being taken from Commonwealth-managed waters and, intermittently, from Tasmanian waters. Ninety-four operators are licensed to take scallops in Victorian and adjacent Commonwealth-managed waters. Vessels are allocated annual quotas that vary with available stock levels. The quotas, which are transferable, are further regulated on a monthly basis (currently ca. 3 tonnes, whole animal weight) to ensure an orderly supply of product to processing facilities and markets. The season is subject to seasonal closures that allow scallops to be taken in the period May – October, when the animals are in optimal condition.

Additional to this fishery, a minor fishery for *P. fumatus* in South Australian waters is managed as a limited entry dive fishery. The fishery currently includes only 4 licensed operators who have produced insignificant amounts of scallop in the past 10 years. The highly intermittent New South Wales and Western Australian *Pecten* fisheries have been managed on an "as-needs" basis in the past. Concerns about the impact of dredging on benthic communities may restrict use of these resources should future recruitment be sufficient to stimulate commercial interest.

4.1.2. Environmental management and sustainability issues

There have been detailed studies of the impact of scallop dredging, particularly in Port Phillip Bay. Currie and Parry (1996, 1999) concluded that dredging had a clearly detectable effect on benthic fauna and topography in the short term, but longer term impacts were far less noticeable. Following the closure of the Port Phillip Bay scallop fishery, environmental management issues were largely directed to the impact of the fishery on the target species. In addition to the 'two spawning' rule, scallop fishing is not allowed when a pre-determined proportion of the catch is smaller than the prevailing size limit in order to minimise wastage. Reducing the impact of scallop fishing on associated benthic communities has been considered in the context of using physically less impacting catch gear (Zacharin 1990b) but still remains a major issue for the industry to address.

4.2 *Amusium balloti*

4.2.1 Regulation

There are marked differences between the management of saucer scallop (*A. balloti*) fisheries in Western Australia and Queensland.

The Western Australian fishery occurs in spatially discrete areas near Shark Bay, off the Abrolhos Islands and, intermittently, to the west and south of Perth. Each area is managed as a separate entity. The collective fishery is managed under a basic tenet that the residual stock levels should not be fished below a level required to maintain long-term recruitment levels despite the absence of any apparent relationship between breeding stock levels and recruitment. Consequently, management of the fishery has been largely focused towards maximising yield, maintaining economic efficiency and minimising conflict with other fisheries that occur in the same locations. This is achieved through limited entry and seasonal closures (Harris et al. 1999). As all product is shucked at sea size limits are not a feasible option for yield optimisation. Entry to the Shark Bay fishery is restricted, with a total of 41 trawlers being authorised to take saucer scallops in this area. Of these, 27 are also entitled to take penaeid prawns and consequently fish for saucer scallops on a part time basis. The saucer scallop fishery is seasonal, with a regulated opening normally occurring in April - May and the season closing in November to coincide with the seasonal closure of a major prawn fishery. In reality, the saucer scallop fishery normally ceases well before November as numbers decline to economically un-viable levels. The Abrolhos fishery is likewise subject to restricted entry and a seasonal fishery regime. Recruitment in this area is far less consistent than in the Shark Bay area, and most of the 16 trawlers that are licensed to fish in this area have access to alternative fisheries. A restricted entry fleet of four trawlers fishes saucer scallops that recruit intermittently on grounds off the state's southern coastline, typically off Esperence, and three trawlers are licensed to take scallops and other trawlable species in grounds west of Perth (34°). Effort in all these fishing grounds is constrained by vessel dimensions and trawl gear size, with trawl size being restricted to a maximum of nets with headrope length no greater than 18 m.

Saucer scallops taken in the Western Australian fishery are shucked as roe-off meat and frozen at sea. Almost all product produced by the fishery is exported, mostly to south-east Asia, where the market offers premium prices for saucer scallop meat (Hart 1994).

The Queensland fishery for saucer scallops is managed as an element of the Queensland East Coast trawl fishery. This complex fishery is largely directed towards the capture of 9 species of penaeid prawn, but also takes crabs, scyllarid lobsters and fish as byproduct, in addition to an average 1100 tonnes of scallop meat a year (Table 2, Fig. 3). While entry to the composite fishery is limited and boat numbers are being reduced, there are still more than 700 licensed trawlers that fish along the eastern Queensland seaboard between about 10°S and 28°S. All of these boats have access to the saucer scallop resource, but only 200 – 300 trawlers report landing scallops in any one year.

The resource is fished heavily. Management procedures are aimed both at yield optimisation and minimising the risk of recruitment overfishing. A seasonally varying size limit and a late winter-early spring closure are used to maximise yield (Dredge 1994). Trawl gear size is limited to a maximum 109 m of (combined) headrope and footrope in order to constrain effort, and three 10'*10' areas that have historically held high densities of saucer scallops have been closed to fishing as a means of maintaining spawner population levels. Saucer scallops are required to be processed ashore, or in a number of designated inshore shucking areas, in order that size limits can be policed.

The bulk of Queensland's saucer scallop production is exported, again largely to south-east Asian markets (Hart 1994).

The marked difference between the Queensland and Western Australian entry policies for saucer scallop fisheries reflect the fundamentally different approaches taken by fisheries managers during the development of Australian trawl fisheries in the 1960s and 1970s. Western Australian managers took a highly precautionary attitude, focused on species-specific management and were committed to a philosophy of developing profitable, flexible fisheries that could fully meet monitoring and management requirements (Hancock 1975). Queensland managers adopted a much more open market philosophy that eventually lead to Queensland becoming a 'dumping ground' for trawlers from a number of other Australian jurisdictions. At one point in time almost 2000 trawlers were authorised to fish in Queensland waters Hill and Pashen 1986). There has been a slow and painful reduction of trawler numbers, but the fishery still has excess fishing effort.

4.2.2 Environmental management and sustainability issues

Both the Western Australian and Queensland saucer scallop fisheries have taken action in recognition of environmental management and conservation issues.

The Queensland scallop fishery is administered under a trawl fisheries management plan that is subsidiary legislation to the State's Fisheries Act. This plan includes trigger points for management intervention, based upon prescribed declines in catch rates of the target species. It includes a number of conservation measures, including limitations on ground chain size, compulsory use of turtle excluding devices, and the (temporary) closure of broodstock protection areas to ensure population levels are maintained. There is a requirement for reduction in bycatch levels, again with associated limit reference points, and a requirement for the fishery to have minimal impact on threatened and endangered species

Western Australian fisheries also operate under management plans that are subsidiary to that State's Fisheries Act. These plans are essentially a set of rules for the fishery's operation. They allow a high degree of flexibility for management responses to changing conditions in the fishery. Bycatch action plans designed to minimise impacts on non-target species are in the process of being developed. More general regional environmental management plans for the fishery are also in the process of being finalised.

5. CULTURE OF SCALLOPS IN AUSTRALIA

While there has been intermittent interest in the culture of scallops in Australian waters, serious commitment to development of mariculture and marine ranching has been limited.

5.1. *Pecten fumatus*

The first recorded investigations into the culture of scallops began in 1917, in Tasmania, when a committee was appointed to inquire into the depletion of scallop beds in the Derwent River estuary (Flynn 1918). The potential for mid-water culture was recognised by this committee, as were the predation problems caused by starfish and crabs. There appears, however, to have been no serious attempt to carry out any form of enhancement until the mid 1970s, when the Tasmanian government established a program designed to assess the feasibility of reseeding depleted scallop beds.

The Victorian, South Australian and New South Wales Governments have invested in pilot studies on the feasibility of scallop mariculture or enhancement. Projects will be described on a state by state basis.

5.1.1. Tasmania

5.1.1.1. Spat production

The feasibility of developing cage culture and enhancement operations using both hatchery reared and wild-caught spat was investigated during the course of a program commenced in 1975. Dix and Sjardin (1975) reported successful rearing of larvae through to settlement, and their techniques were successfully applied to other scallop species (Dix 1976, Rose and Dix 1984). Whilst hatchery experience and competence have been developed to the point that commercial oyster and abalone operations rely on their output, there is currently no hatchery producing scallop spat at commercial levels (Crawford, Tasmanian Scallops Pty Ltd. pers. com.). Spat collection rates in mesh bag collectors placed off the Tasmanian east coast were initially very low (Dix 1981, Hortle 1983), but improved with time and experience to reach up to 400 spat per collector (Hortle and Cropp 1987).

5.1.1.2. Culture operations.

The Tasmanian Government entered into a joint-venture agreement with the Japanese Overseas Fisheries Foundation in 1986. Under this agreement, the Japanese organisation supplied technical expertise and capital for scallop mariculture, while the Tasmanian government provided research capacity, infrastructure, staff resources and an exclusive lease area in and adjacent to the Great Oyster Bay (Fig. 1). Thompson (1990) gives a brief account of the joint venture's progress.

The joint venture initially used open water spat catching techniques to obtain spat, and followed well described procedures of hanging cage culture for rearing spat, using cage culture and intermediate culture techniques as described by Ventilla (1982). The operations were not immediately successful. Short falls in spat supply and cage fouling was reported to be major constraints to growth and economic production of scallops.

The operation changed organisational structure and direction, being largely taken over by a Japanese consortium and moving towards an open water seeding operation. Open water seeding had limited success, as spat supply from both open water collectors and hatcheries was limited to between 5 and 20 million spat per year, and natural mortality rates appear to have been very high. Annual production has not exceeded 50 tonnes. Following further restructure, the operating company is now re-directing efforts towards hanging cage culture, and is investigating the feasibility of mariculture for other molluscan species, as spat supply continues to be a limiting factor for scallop culture.

5.1.2. Victoria

While there has been intermittent interest in the potential of cage culture within the protected waters of Port Phillip Bay, there has been little serious commitment of money or material to such operations. Spat catchers were deployed in the Bay during the 1980s as a means of monitoring spatfall for predictive fishing models (Coleman 1990). Mercer (Victorian Marine and Freshwater Institute, pers. com.) has renewed spat collection in a pilot project to assess the potential for supplying a scallop aquaculture industry in the Bay He obtained catches of up to 400 spat per bag in areas of eastern Port Phillip Bay in 1998 and 1999. An existing mussel farming operation has at least some of the infrastructure requirements for scallop culture work in Port Phillip Bay. Progress of this work to a pilot scale operation will depend upon State Government policy development in relation to the desirability of mariculture operations in what is regarded as an environmentally and socially sensitive area.

5.1.3. New South Wales

Pecten fumatus intermittently settles in large numbers along the southern coast of New South Wales. Short-lived fisheries in areas such as Jervis Bay (Fuentes 1994) have occurred as a consequence of these settlements.

There has been some interest in establishing whether the population could be stabilised through enhancement procedures, using hatchery-reared spat. There has been considerable progress in developing hatchery procedures for mass rearing of *P. fumatus* spat in hatcheries (Heasman et al. 1994, Heasman et al. 1998), but there has been little progress towards the development of a commercial cage culture or enhancement. An early (pilot) attempt to establish a bottom seeding program was unsuccessful, with predators, including rays, causing substantial losses to the stocked out population. Concerns about the environmental consequences of dredging seeded scallops may limit future restocking operations.

5.1.4. South Australia

There have been two commercial attempts to develop *Pecten* mariculture operations in Southern Australian waters. Both occurred in the period between 1996 and 2000, and were based on the concept of using spat collected from open waters in cage culture operations, in waters to the north of Kangaroo Island. Little has been documented about either operation, but the initial attempt apparently closed following two seasons of unacceptably low spat numbers being collected (Young, pers. com.). An attempt to revive this operation is in an early stage of development.

5.2. *Amusium balloti*

The rapid growth rate and high market value of *A. balloti* suggest the species has inherent potential for mariculture and enhancement operations. There has been some research but little commercial commitment to translate this potential to reality. The apparent absence of anything more than a transient byssal attachment in this species (Robins-Troeger and Dredge 1993, Cropp 1994) limits the scope for wild spat collection. Consequentially any fisheries enhancement or mariculture operation would be reliant on hatchery reared spat.

Rose et al. (1988) reported on initial attempts to develop hatchery techniques for breeding *A. balloti* under controlled conditions, and Cropp (1992, 1994) attempted to expand on this work to develop an operational model for saucer scallop enhancement in Western Australian waters. While his work was not immediately productive in a commercial sense, there have been further attempts to enhance saucer scallop populations using hatchery-reared spat. The Western Australian government have granted an exclusive-access seabed lease in coastal waters at about 29°S, inshore of Abrolhos Islands, and a private venture company has established a hatchery as part of an program to generate a commercial bottom seeding operation (Joll pers. com.). There appears to be some scope for companies currently raising pearl oyster (*Pinctada maxima)* spat to diversify into *Amusium* culture should the present program achieves commercial success.

6. SUMMARY

Australian fisheries for scallops have been based on two species groupings and the fisheries that have evolved from these two resources have taken very different paths. The southern Australian dredge fishery for *Pecten spp*. has gone through the ‘booms and busts’ that appear to characterise many scallop fisheries. This fishery, however, appears to face difficulties and challenges of unprecedented magnitude. Recruitment in some previously productive areas has failed for an extended period of time, and the fishery has been based on scallop populations with a much reduced age structure than has been the case in historical times. Some parts of the fishery have been closed to meet social and environmental requirements, and the surviving elements still face major challenges in meeting the stringent environmental and sustainability standards associated with Australia’s recently developed fisheries management standards.

The trawl fisheries for *A. balloti*, on the other hand, have been far more stable in terms of landings. Apart from the three years of massive landings from Western Australia when environmental conditions apparently improved recruitment, and a marked decline in Queensland in 1996, possibly associated with overfishing, annual landings have remained relatively stable by the standards of most scallop fisheries. These fisheries still need to address environmental sustainability issues, but have gone some way to meet these requirements.

By global standards, aquaculture and enhancement operations in Australia have received little commitment and met with little success to this time.

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